Western Australian Institution of Engineers.

PROCEEDINGS

VOLUMES VIIa, VIII and IX.

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PROCEEDINGS

OF THE

Western Australian Institution of Engineers.

(INCORPORATED)

VOLUMES VIIa, VIII, and IX.

FEBRUARY 1, 1917, TO JANUARY 31, 1919.

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AT PERTH, WESTERN AUSTRALIA,
1919.

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WESTERN AUSTRALIAN
Institution of Engineers

(INCORPORATED).

REPORT OF THE COUNCIL.

Session 1918-1919.

The Council beg to present the Eighth Annual Report and Balance Sheet.

Membership.—The number of members on the roll is 110.

Meetings.—During the session six general and six Council meetings were held, the attendance at the Council meetings being as follows:—C. E. Crocker (3), H. Dowson (3), E. A. Evans (3), G. E. Farrar (3), J. R. W. Gardam (6), H. T. Haynes (5), W. J. Hancock (3), E. S. Hume (1), E. E. Light (1), W. Leslie (1), P. V. O'Brien (1), J. Parr (4), R. A. Rolland (4), F. E. Shaw (1), W. H. Taylor (6), A. Tomlinson (2), A. Ventris (5).

In addition, several meetings were held to consider the proposed constitution of the Institution of Engineers of Australia.

Business dealt with at Council Meetings.—The principal business dealt with by the Council was: the consideration of the finances; the collection of subscriptions in arrears; arranging for papers to be read at the general meetings; consideration of applications for new members and adjusting the roll of members.

The standardisation of structural steel was also considered by the Council, and Mr. E. A. Evans was appointed to represent the Institution at a conference to be held in Melbourne to consider the matter.

A conference was also held at the rooms of the Institution, the President, Mr. J. R. W. Gardam, presiding, to discuss "Engineering Standardisation in Australia." Twenty-one delegates attended the conference, and it was resolved that the British standards should be as far as possible adopted in Australia, in preference to setting up separate standards. The conference also passed the following resolution:—"That this meeting protests against electrical standardisation in Australia being left to the Electrical Association of Australia, and requests that Western Australia has equal representation."

Western Australian Institution of Engineers.

BALANCE SHEET FOR YEAR ENDING JANUARY 31st, 1919.

Receipts.	£ s. d.	£ s. d.
To Balance forward		73 11 3
,, Subscriptions—		
Members	132 12 6	
Associate Members	12 11 6	
Associates	9 9 0	
Students	2 2 0	
		156 15 0
,, Refund from Sydney		21 0 0
		£251 6 3

Expenditure.	£ s. d.	£ s. d.
By Secretary		39 0 0
,, Rent		24 6 8
,, Printing and Typing		1 10 6
,, Stationery		5 10 0
,, "Proceedings"—		
Blocks	3 18 1	
Lantern	3 3 0	
Clerical Assistance	2 0 0	
		9 1 1
,, Postages and Sundries		7 10 5
,, Delegates to Sydney		80 0 0
,, Advertising		1 2 6
,, Bank Charges		10 0
,, Bank Balance and Cash in Hand		82 15 1
		£251 6 3

STATEMENT OF ASSETS AND LIABILITIES.

Liabilities.	£ s. d.
Rent: Master Builders	2 0 0
,, Commercial Union	6 5 0
Secretary's Salary (Nov., Dec., Jan.)	13 0 0
Jones & Co.	11 3
W.A. Newspaper Co.	15 0
Sandover & Co.	3 7
Balance	215 15 9
	£238 10 7

Assets.		£ s. d.
Bank Balance and Cash in Hand		82 15 1
Subscriptions Due and Arrears		144 15 6
Furniture	£6 7 0	
Less Written Off	7 0	
		6 0 0
Library		5 0 0
		£238 10 7

G. E. FARRAR, *Acting Hon. Treasurer.*
W. B. SHAW, *Secretary.*

February 24th, 1919.

Audited and found correct.

J. ANDREW,
L. HELFFENSTEIN, } *Hon. Auditors.*

Papers.—The following papers were read during the session:—

"Presidential Address" by Mr. J. R. W. Gardam.

"Engineering Problems in Ancient and Modern Gunnery," by Professor A. Ross.

"Evolution of Coining Machinery," by Mr. A. Ventris.

"Electric Power on the Kalgoorlie Mining Field," by Mr. C. E. Crocker.

"Electrification of Railways," by Mr. W. H. Taylor.

The above papers, with others read previously, are now being printed, and the Council request that members will prepare papers for the ensuing session and at once notify the Secretary of the titles of their papers.

Visit to the Fremantle Smelting Works.—Through the courtesy of Mr. W. Sutherland, the members of the Institution visited the Fremantle Smelting Works, and were greatly interested in the process. Arrangements will be made during the year for visits to other places of interest.

Students.—As the war is now over, the Council hope that all the students of the Institution will soon return and be present at the meetings, and that there will be keen competition for the prize of £2 2s. donated by Mr. W. J. Hancock, to be competed for among the students. The Council will shortly announce what form the competition will take.

Proposed Amalgamation of the Institutions of Engineers of Australia.—The Institution sent two delegates, Messrs. H. T. Haynes and the Secretary (Mr. W. B. Shaw), to the conference held in Sydney in May, 1918. The delegates reported that the conference was unanimous in recommending the formation of an Institution of Engineers of Australia. The conference sat for two days and nights, and drew up a basis of a constitution. A special committee was appointed by the conference to draw up the proposed constitution in legal form, then to forward same to the delegates. This was done, and the constitution was carefully considered by your Council and the delegates, who made certain recommendations, the majority of which were adopted. The special committee then further considered the recommendations of the various councils and delegates, and forwarded a revised draft, which was again considered by the various councils and delegates, and their recommendations forwarded to the special committee. The President of the Conference has reported that the differences of opinion are now very small, and it is expected that the final draft, approved of by the Councils and delegates of the various Institutions, will shortly be placed before all members for their approval.

Financial.—The balance sheet shows that the excess of assets over liabilities is now £215 15s. 9d., which is only £8 less than last year, although the expenses of the delegates to the conference at Sydney was £69. The Council hope that members will pay their subscriptions promptly, as they consider the time has arrived for the Institution to have a reserve fund, which could at once be accomplished if all the subscriptions due were paid up.

General.—The Council consider that all engineers must recognise that it is urgent for their profession to have better recognition than it has at present, and they express the hope that, as the war is now over, all members will take a keen interest in the affairs of the Institution in order to bring this about.

Roll of Honor.—H. B. Bennett, G. Drake-Brockman, A. C. Cooper,* W. D. Evans, S. E. Evans, M.C., W. R. Easton, R. R. Farrar, A. J. Hillman, A. W. Johnson, H. Kelly, G. R. Kerslake, F. W. Lawson, W. Leslie (Junr.), J. Pidgeon, J. H. Playne*, L. W. Poole, I. A. Ridgeway*, B. E. W. Thomas, W. Thomasson, W. G. Townsend, R. H. Viner.

* Killed in action.

Western Australian Institution of Engineers.

(INCORPORATED)

CONTENTS.

VOLUME VIIA.

VOL. VIIA.

PROCEEDINGS—WESTERN AUSTRALIAN INSTITUTION OF ENGINEERS.
(Incorporated)

PAPERS AND DISCUSSIONS.

The Institution is not responsible, as a body, for the facts and opinions advanced in any of its publications.

GENERAL MEETING HELD AT THE INSTITUTION'S ROOMS ON APRIL 5, 1916.

PRESIDENTIAL ADDRESS.

By E. A. EVANS.

I would first express my very sincere thanks for the honor you have conferred by electing me to the position of President of this Institution for the ensuing year. Since the initiation of the Society some nine years ago, it has been my pleasure to take an active interest in all your proceedings, and in accepting the position of President of the Institution I can assure you I am actuated by the keenest desire to promote its interests to our general advantage.

I am not unmindful of the fact that the senior Vice-President of this Institution has considered it his duty to accept a commission in the Australian Imperial Forces, and is now serving his King and Country, and but for this no doubt Captain Lawson would have this year received the honor you have conferred upon me. His action is one we all highly appreciate and admire. and it is our sincere hope that he will safely return to us, and that we may be privileged to place him in the position of President.

We must not forget that this world-wide war has made calls for men in all directions to maintain and uphold our glorious privileges against a wanton and relentless enemy. Our State has nobly answered the call, and this Institution has sent of its best. We have supplied the Forces with a Major and a Captain of Engineers, both of whom were senior members.

Members and students have also left us to do battle for the grand cause. Some of our youngest members, who were with the First Contingent in November, 1914, and fought in the first attack of the Turks on the Suez Canal, were amongst the first landing parties to set foot on Gallipoli, and helped to make history, and an unforgetable name for Australia at Anzac. Some of them I am proud to say stayed right through and left that untenable shore in the last boat. It is our hope that they may in good time return to us safe and sound to receive direct the expressions of pride and feelings we have towards them.

An inspiring sight was to see the valiant Miners' Corps, so recently here, and more particularly to observe amongst them that grand example, Professor David, Engineering Professor of Sydney University, the hero of Antarctic fame, who planted the Union Jack at the South Magnetic Pole, and now, when he is fast approaching the allotted span, again goes forth to risk his life on the battlefield for that which you and I all hold dear. It is good to belong to an honorable profession which counts such as Professor David amongst its foremost members.

I feel that no apology is needed at this present time for so many references to this war. It has incessantly occupied our foremost thoughts for the past eighteen months, and the end does not yet appear in sight. It is freely admitted on all sides that this is an engineers' war, and all the devilish ingenuity of man has been pressed into the service. We are all aware of the engineering abilities of our enemies where the arts of peace were employed—many splendid examples of their brains and brawn are to be found all over Australia—and we now know that they have devoted the same forces in the preparation for and prosecution of this war. Never again while this generation breathes should a German be received into this fair country in the way we formerly received him. He was welcome, he enjoyed all our social and political privileges, and we hesitated not to buy his goods. It is now for engineers to see that British goods are what we want and what we intend to get when we cannot make them ourselves.

As I find myself getting very near to politics, I will now devote the remainder of my remarks to a subject very pertinent to the occasion, viz., the manufacture of the British pattern 18-pounder high explosive shells.

Much original thought has been given to this question, and many new and ingenious devices have been perfected in this State for the production of shells. Prior to August, 1914, few of us were interested in military ammunition and most of us were very ignorant of what was required by our Forces. True to our calling, however, it was considered that we could do

something in Australia towards supplying the needs of the Minister for Munitions. At first the difficulty was to obtain the raw material, and many pessimists declared that it could not be produced out here. The newly formed Broken Hill Proprietary Works at Newcastle, New South Wales, however, tackled the proposition, and have produced an excellent steel. The Company is capable of turning out more shell steel than could be worked up in Australia. This steel has been analysed and tested, and meets the specifications in these respects, but what seems to me to be ultra-refinements are demanded in other directions, and these are not yet satisfied. This, gentlemen, is one great step forward in the making of a self-reliant nation.

Before the bar steel could be converted into shells there were many knots to be unravelled:—Which of our machines were suitable? and for which operation? It was well known that no machinery could be purchased in England for the purpose, as its export was prohibited and the output of the makers commandeered by the Home Government. The United States and Canada were in turn tried, but they either could not supply or else could give no reasonable date for delivery. We had machinery of a kind and that only working eight hours out of the twenty-four. It was therefore obvious that we must rely on our own resources and either convert or make what was necessary. In the whole of the workshops with which I am associated there were only two machines which could be utilized for any part of the manufacture of shells without extensive alterations and additions, and only one of these could possibly be given over to this work.

The first question was to decide for ourselves how the various operations, numbering over twenty, were to be performed and in what sequence. Having arrived at a decision on these points, machinery had to be altered, added to, or made entirely to meet the necessity.

The following list gives the sequence of the operations as decided upon to suit our particular means of manufacture, and obviously were largely controlled by how we could do it:—

Parting off from bar into two shell lengths.
Centring.
Body turned.
Nosed.
Parted off.
Rough bored.
Finish bored.
Nose screwed.
Grooved.
Base holed.
Drill grub screw holes.

Turning base plugs.
Base plug rivetted.
Press band.
Turn band.
Adjust for weight.
Varnish.
Bake.
Screwing nose plugs.

The steel, 3½-in. diameter in bars of about 21 ft. long, was received at the works. Straightening the bent bars was objected to if heat was applied. In their bent condition they would not go through a hollow spindle lathe; it was therefore necessary to cut them into two in the slotting machine.

The next operation was performed in a No. 4 Herbert Turret lathe. Double billets to make two shells were parted off the bar, a nick was cut in the centre and the arris taken off both ends in the one operation. These billets weighed 56 lbs. each. No serious alterations were necessary to this machine. The hollow spindle was bored out, as its original capacity was for 3-inch bars.

A small machine was converted and adapted for automatically centring both ends of the billet simultaneously and boring the centre about ½ in. deep, to ensure the drill getting a true and fair start.

It may here be remarked that each time a bar was parted or billets cut up the stamping to denote the cast of the steel and bar had to be transferred to each individual part, so that at any time if serious faults were discovered the whole of a cast could be found if necessary and condemned.

The pair of billets were now transferred to a 12-in. Lang lathe, where the outside was roughed down in two cuts. A small auxiliary turret was added to the cross slide rest of this lathe. This enabled the two tools required to be brought into operation in a quick and convenient manner.

Having roughed down the billet, it was passed on to the finishing lathe, where the proper size was produced within the limits allowable. This lathe was also equipped with an auxiliary turret, as before described.

To complete the exterior body of the shell, the reduction of the nose end was next performed. A radical alteration to the slide rests of this machine was necessary. The screw for the cross feeder was removed. A former-plate was attached for guiding the roughing out tools, giving the nose the approximate radius, two tools were again held in an auxiliary turret. Having roughed out the nose, a form tool attached in a vertical slide at the back of the lathe was brought into work;

this tool automatically finishes the nose to the correct contour.

The pair of billets are here returned to the Herbert lathe, where they are parted into two.

At this stage, the steel being bright and clear all over, is rigidly examined for any surface defects or cracks, or for piping at the ends. Any sign or suspicion of a hair crack or flaw in the shell warrants condemnation of the piece.

The heaviest operation is next taken in hand, viz., the rough boring of the shell. This means reducing its weight from 24 lbs. to 16 lbs. For this purpose a 3-spindle drilling machine was selected and radically altered. The original 3-in. belt drive was converted to a 6-in. belt, a pump for forced lubrication was added, and under each spindle was attached a self-centring chuck, which ensured that the bore was truly concentric with the outside of the shell. The hole was bored out to $1\frac{3}{4}$ in., leaving only $\frac{1}{8}$ in. to finish. It is of the utmost importance that this rough hole be truly concentric and to the proper depth, as to adjust any irregularity in either respect in subsequent operations was both tedious and costly. The small diameter of the hole, with its considerable depth, precluded the use of a rigid boring bar or tool, hence the difficulties. In this machine three shells were bored simultaneously and satisfactorily.

The succeeding portion of the work caused the greatest amount of trouble before a successful issue was obtained, *i.e.*, to finish bore the hole and square out the bottom to correct contour and depth. A good finish is demanded in the bore; the bottom must be absolutely to the correct contour and smooth. Many attempts were made to perform this operation with the usual double-sided flat cutter in the end of a bar. When this cutter came in contact with the bottom of the hole the additional cutting surface sprung the cutter up or down, with the result that a pocket was cut in the walls of the shell. A successful result was eventually obtained by grinding off the point of a twist drill to the correct contour, this drill being the size of the hole in the shell was supported all down the bore, and a good finish was the result. The lathes for this operation required many additions; the carriage was equipped with a substantial turret fitted with eight separate tools, which are readily swung into position for each portion of the work. It is not always necessary to use all of these tools, but any slight deviation when rough boring required them all to rectify the defect. The driving belt was increased in width 50 per cent. and two speeds were obtained on the countershaft. A draw-in Collet chuck was designed for holding the shell.

To complete the interior of the shell the nose end has to be screwed, a check cut at the inner end of the screw, and a

precise bevel and check on the outer end to fuse case. These several items are produced at one setting, the screw being cut in the lathe and finished to dead size with an expanding tap.

The groove with twin wave projections in same is next in order. The groove is roughed out with a tool on the front rest, and the sides of the groove under cut. On the chuck carrying the shell is a cam groove operating a tool at the back of the lathe to produce the wave bands. These wave bands are designed to prevent the copper band rotating when passing along the rifling in the gun barrel.

The shell is passed to another lathe equipped with a special chuck and turret, where the base of the shell is bored out to receive a base plug, to be eventually rivetted in. The base plug is put in to overcome the possibility of any piping in the shell, whereby any gases from the propelling charge could get into the high explosive and so cause a premature explosion in the gun.

The copper band being prepared, is now pressed into the groove by means of a six-cylinder hydraulic press, the pressure required being about ten tons to the super. inch area of the band. This machine was designed and made at the works. The frame consists of two old engine tyres. A safety valve is provided to release the pressure at the prescribed amount. The action of this release introduced an undesirable kick on the gauge, which was overcome by the introduction of suitable diaphragms and holes in same to nearly equalize the incoming and outgoing pressure of water.

A sand blasting machine to operate on three shells at once was designed and made in the shops. This is used in the next operation, to thoroughly clean the band groove prior to putting on the copper band.

To rivet in the base plug a pneumatic hammer has been specially arranged, the hammer head being so made that a blow is struck simultaneously on opposite sides of the rivet, preventing the possibility of tilting or canting the plug. Perfection is demanded in this operation as regards the size of the hole, flatness and smoothness of the base, the fit of the plug and that the rivet is absolutely driven home all round.

The copper band has now to be turned to the prescribed profile with no less than seven separate members and five dimensions, all of which are deemed to be of the utmost importance and must be to size.

There now remains several subsidiary operations, the most important being the varnishing, after sand blasting, of the interior of the shell, and baking same at a temperature of 300° F. for eight hours. For this purpose an electrically heated oven was designed and made to treat 75 shells at once. The

nose of the shell is bored and tapped to take a $\frac{1}{4}$-in. grub screw, which secures the fuse. To protect the interior varnish from damage a cast iron plug is screwed into the nose of the shell. After machining, the cast iron plug is nickel plated to prevent oxidization.

During all these operations the viewers handle the shells and minutely inspect them for surface defects, and that they are true to gauge and within the prescribed limits, and finally that they are within the limits for weight.

The plant described was put down for an output of six to eight shells per hour. It has, however, been added to since, and this process is continually going on.

To have purchased a plant for this output would have cost at least £5,000. The cost to move these machines, make all the gear, jigs, chucks, and special tools of all descriptions has been done for less than a third of that amount.

In conclusion, I have again to thank members for the honor bestowed upon me, and also to acknowledge the facilities given me to prepare this paper by my chief, Mr. Hume.

General Meeting held at the University of W.A. at Perth on September 6, 1916.

THE PROBLEM OF CORROSION.

By N. T. M. Wilsmore.

In opening a discussion on the corrosion of metals before the Faraday Society last December, Sir Robert Hadfield, the President of the Society, began with the following words:—" In the presentation of this symposium of papers on the interesting subject of 'Corrosion,' it can be quite correctly stated that there is no more important subject than this study of man's fight against Nature, whether on land or sea. It has been estimated that the losses of the iron in the world by corrosion amount to hundreds of thousands of tons annually. Man at great pains smelts the iron taken from Mother Earth, and produces what is termed 'metal.' Nature immediately sets to work to destroy man's handiwork, and, except in certain favored spots of the world, she generally conquers." The economic importance of the subject is, however, still more apparent when it is remembered that to the enormous wastage of manufactured metal due to corrosion which is continually going on, must be added the heavy cost of the various protective coverings which are applied with a view to preventing it, usually with but indifferent success. Thus, in one structure alone, the Forth Bridge, the total area which has to be painted is said to be 145 acres. Hence, although a very concise resume of previous work on corrosion was contributed to the Western Australian Institution of Engineers by Mr. E. A. Mann in 1912, little apology is needed for again taking up the subject, more especially as much valuable work has been published in the interval. In fact, the subject is so large that, even without traversing ground already covered by Mr. Mann, space will permit of only the briefest outline of the various aspects. Fuller information may, however, be obtained from the following sources:—" The Corrosion and Preservation of Iron and Steel," by Cushman and Gardner; " The Corrosion of Iron and Steel," by J. Newton Friend; the series of papers published under the title " The Corrosion of Metals, Ferrous and Non-Ferrous," in the Transactions of the Faraday Society, 1916, Vol. IX, pp. 183, *et seq.*, and the Reports of the Corrosion Committee of the Institute of Metals, which may be found in the Journal of the Institute.

Corrosion may be broadly defined as any chemical change by which the metal is converted into another substance possessing little or no mechanical strength. The corrosion of iron and its alloys, however, outweighs in economic importance that of all other metals, firstly because the use of iron far exceeds that

of other metals, and secondly because iron is more easily attacked by atmospheric and similar influences than most of the other common metals. In the case of iron and its alloys, the term "corrosion" is frequently restricted to the phenomena which are usually grouped together under the term "rusting," by which is meant the progressive conversion of the metal at the ordinary or a moderately elevated temperature, chiefly into hydrated ferric oxide. For preventing the corrosion of structural iron and steel, reliance has hitherto been placed for the most part on the application of various forms of protective covering. This is, however, at best but a very imperfect method. All protective coverings are liable to mechanical injury and most of them are themselves sooner or later destroyed by the various influences to which they are exposed. Also many protective coverings, such, for instance, as mill scale, tin or certain forms of oil, varnish, when discontinuous, actually stimulate the corrosion of the exposed metal. The ultimate solution of the problem must be sought in the production of such changes in the metal itself as shall enable it to resist corrosive influences. Unfortunately, in spite of the great amount of research work which has been and is being done with this object, little or no progress in this direction has as yet been made, so far at any rate as iron and steel for structural purposes are concerned. It is true that several alloys of iron have been discovered which are highly resistant to corrosion, but their economic usefulness is strictly limited. For structural purposes, either they are far too costly, or their mechanical properties render them unsuitable.

The survival of examples of ancient ironwork, such as the famous Delhi Column and the chains fixed for the assistance of pilgrims to Adam's Peak in Ceylon, which have braved the elements for centuries without visible corrosion, might seem to imply that we have only to re-discover some secret process which was known to the ancient metallurgists, but which has since been lost. Careful analysis shows, however, that there is nothing peculiar about the composition of these specimens, and it would seem that their immunity from attack is due to layers of cinder worked into the metal by the crude methods of forging then in use. Corrosion appears to have gone on until one of these layers was reached, and to have been then arrested. A similar effect has been observed in specimens of puddled wrought iron, layers of mill scale being worked into the metal in the process of doubling and rolling. Such a coating very soon breaks down under the stresses and vibration which modern structures have to bear, and when fresh surfaces of the ancient metals are exposed, rusting is found to proceed just as rapidly as, if not more so, than with modern iron or steel. It may be mentioned, however, that amongst the

more resistant of the alloys of iron are those containing a high percentage of silica, and it has been suggested that if some form of case-hardening could be devised in which silica was incorporated instead of carbon, effective resistance to corrosion might be secured.

Various hypotheses have been put forward from time to time to explain the mechanism of the rusting of iron, but only two of these are worth serious consideration, and even these two are not antagonistic, but complementary, to each other. These are usually called the " acid " and the " electrolytic " hypotheses, respectively. According to the " acid " hypothesis, the iron is primarily attacked by some acid in solution, usually carbonic acid, with the formation of a ferrous salt and hydrogen. The " electrolytic " hypothesis accepts the teaching of modern physical chemistry, that even in the case of acids in which all the hydrogen may be ultimately replaceable by a metal, such as hydrochloric, sulphuric, or carbonic acids, only a portion of the hydrogen is in an active state in solution. When the acid is dissolved in water (or in one of a limited number of other solvents), a certain fraction of the acid molecules, depending on the nature of the solvent, etc., are split up under the influence of the solvent into electrically charged positive and negative particles. These charged particles were called by Faraday " ions," or wanderers, since they move in an electric field, and are in fact the carriers of the electric current which is set up when an electromotive force is applied to an electrolyte. The formation of these charged particles is known as " ionization." Besides acids, soluble bases, such as caustic soda or lime, and neutral salts such as sodium chloride, are also ionized in solution, and will therefore conduct an electric current. In the case of acids, the positive ions (cations) are positively charged hydrogen atoms, the negative ions (anions) being the remaining portion of the original acid molecules which have received negative charges. In solutions of soluble basis, the cations are usually metallic atoms, positively charged, whilst the anions consist of hydroxyl with a negative charge (O H—). When an acid is added to a base, the hydrogen ion of the acid combines with the hydroxyl of the base to form water, which is chemically and electrically neutral, the anion of the acid and the cation of the base remaining in solution and forming now the ions of the salt which has been produced. From the results of physical chemistry we must conclude that water itself is an electrolyte, although an excessively feeble one, only a minute fraction of its molecules being ionized at any one time. As an electrolytic medium, water occupies a peculiar position, seeing that on ionization, hydrogen ions and hydroxyl ions are produced in equal quantities. Water is therefore both

an acid and a base at the same time. Thus it will react with many metals, such as sodium or calcium, according to the equation—

Metal+hydrogen ion=metal ion +hydrogen

the hydroxyl being now the anion of the base which has been formed. On the other hand, water will re-act with strong acid-forming elements, such as chlorine or fluorine, chlorine ions or fluorine ions being formed, and an equal amount of hydroxyl ions being discharged. (What happens to the discharged hydroxyl need not concern us here.) All aqueous solutions therefore contain both hydrogen and hydroxyl ions. But since the amount of ionization of water is very small, in all dilute solutions the concentration of the anionized water is practically constant, from which can be deduced (by a process of reasoning which space forbids me to reproduce) that the product of the concentrations of the hydrogen and hydroxyl ions in all dilute aqueous solutions must also be constant. That is, if we increase the concentration of hydrogen ion by adding acid, that of the hydroxyl ion must decrease in like proportion, and *vice versa*. This result has an important bearing on the rusting of iron.

Although in any electrolyte only a portion of the molecules are ionized, still the ions are in equilibrium with the ionized molecules, so that, if any of the ions are removed from solution, more must be found by ionization of the neutral molecules until the latter are used up. Thus, although pure water contains very few hydrogen ions, if any of them are discharged more can be formed from the residual water, along with an equal number of hydroxyl ions. Similarly for acid molecules. The electrolytic hypothesis of rusting is thus merely an extension and development of the older "acid" hypothesis. In the first place, the initial attack of acids on iron is referred to the hydrogen ions; in the second place water, being a source of hydrogen ions, must be regarded as an acid, if only a feeble one. On the older view, the action of water on iron would be described as giving ferrous hydroxides plus hydrogen, or—

$$Fe+2\ H_2O=Fe\ (O\ H)_2+H_2$$

On the electrolytic hypothesis we have: iron plus hydrogen ions form ferrous ions plus hydrogen, or—

$$Fe+2\ H^+ = Fe^{++}+H_2$$

The tendency of a chemical reaction to take place is increased by increasing the concentration of the re-acting substances, and decreased by increasing the concentration of the products, although the effect of the latter is not so marked in the case of irreversible re-actions. The attack on the iron, therefore, should be stimulated by increasing the concentration of hydrogen ion, and retarded by increasing that of ferrous

ion and gaseous hydrogen. Thus, when water or a solution which is very feebly acid acts on iron, the re-action will quickly be brought to a standstill. In the first place, the H+ ions will be rapidly used up until their concentration reaches that proper to pure water, after which ferrous hydroxide will begin to form. As this substance, although sparingly soluble, is much more completely ionized than is water, hydroxyl ions will be formed along with ferrous ions, and in consequence the concentration of H+ ions will get smaller and smaller. In the second place, the liberated hydrogen tends to form a protective film on the surface of the metal.

Here, however, comes in the second factor in rusting, the oxygen of the air, which acts in two ways, firstly by removing both ferrous ions and hydroxyl ions from solution and forming with them hydrated ferric oxide (rust)—

$$4\,Fe^{++} + 4\,OH^{-} + O_2 = 2\,Fe_2\,O_3\,2\,H_2\,O.$$

Secondly by oxidising the hydrogen as fast as it is liberated—

$$2\,H_2 + O_2 = 2\,H_2O.$$

For ordinary rusting, therefore, the action of both water and oxygen is necessary, but of course in the presence of acids, and of salts like magnesium chloride, which readily act on water to form acids, the metal may be corroded in absence of free oxygen. In the lattercase, however, if oxygen be afterwards admitted, the ferrous ions in solution will usually be oxidised to rust, as before.

Effect of External Conditions on the Corrosion of Iron.

Air or oxygen, even in the presence of small quantities of water vapour, has no sensible action on iron until a temperature approaching 200° C. is reached. The characteristic films of oxide then begin to form, the colour of which is taken as a rough scale of temperature in tempering steel. As a measure of temperature, the colour is only permissible if the time of heating and the nature of the metal are fairly uniform. It is possible, for instance, to obtain a deep blue by prolonged heating below 200° C. On heating to high temperatures, the coating of oxide becomes thicker, forming the well-known "mill scale." The oxide films produced in this way consist chiefly of the black magnetic oxide, which is a somewhat inert substance.

The same oxide is produced when iron is heated in steam in absence of air to temperatures above about 350° C. This is the essence of the Bower-Barff process for producing a black finish on iron and steel. So long as the coating is intact, the metal is well protected against corrosion unless exposed to strong acids, but if the film is broken through, the exposed metal will rust rapidly.

It is found that iron does not rust in moist air unless the temperature falls below the dew point and liquid water is actually condensed on the surface of the metal. Specimens have been preserved in European museums for many years simply by maintaining the temperature of the room above the dew point. Since at a given temperature the vapour pressure of water in capillary space is less than at a free surface, it follows that dew will deposit at a higher temperature in capillary space for a given amount of moisture in the air. Hence the well-known fact that a polished surface rusts less easily than a rough one of the same metal. The stimulating effect on rusting of rust itself is also partly due to this cause. The fact that " busy " iron or steel, such as railway rails in constant use, rusts less rapidly than metal which is lying idle, is probably due to the rust being shaken off as fast as it is formed. The protective action of oil and grease is due to their water repelling nature, although they are permeable to air and water vapour.

As oxygen is necessary to rusting, the concentration of the oxygen in the air or dissolved in the water influences the rate of attack. Hence rusting goes on rapidly " between wind and water," but much slower in deep (fresh) water or in deep wells, where the oxygen cannot be so quickly renewed. For the same reason, rusting will go on faster inside a pipe through which water is flowing than when the water is still, as in a dead end. De-aeration of boiler feed water is an effective means of preventing corrosion, provided free acid, or a salt which gives rise to free acid, with water, is absent. Otherwise alkali should be added as well.

Corrosion is markedly stimulated by the action of light. Rise of temperature should also increase the rate of attack, were it not that gases (oxygen, carbon dioxide, etc.) become less soluble in water as the temperature goes up.

Biological influences are sometimes of moment. The growth of certain bacteria is greatly stimulated by the presence of iron in the soil, and colonies of such bacteria are sometimes found on the buried parts of iron structures, and by secreting acids stimulate the corrosion of the structures. Acids are also secreted by earthworms, and by the roots of plants.

The effect of substances in solution is of great importance, even when such substances are themselves left unaltered by the corrosion of the metal in contact with the solution. Some substances stimulate, others (called by Cushman " inhibitors ") retard corrosion; but it frequently happens that the same substance will fall under one head or the other, according to its concentration. The inhibiting action of alkalis such as caustic soda, lime, or even ammonia, if not too dilute, is well known. The action of these substances is obvious. Seeing that

they ionize in solution forming hydroxyl ions, the hydrogen ion from the water is reduced to an excessively small concentration. The first effect of the addition of a neutral salt is usually to stimulate corrosion, but, after a particular concentration, the "critical" concentration is reached, further increase in concentration lessens the rate of attack towards zero, the "limit concentration" being then reached. The actual amounts of the critical and limit concentrations will depend on the nature of the salt, temperature, etc. In the case of some salts, such as sodium carbonate, the drop in the rate of corrosion from the critical to the limit concentration is very rapid. This is of some interest in connection with boiler water which has been softened with sodium carbonate, as some excess of this salt is frequently present. Obviously, the concentration of the sodium carbonate should be either very small or well above the limit. As both the critical point and the limit are at a concentration of about 0.1 per cent., it would seem to be undesirable to blow off the boiler too frequently. In the case of very many salts, of which sodium chloride is an example, however, the critical and limit concentrations lie much further apart. In fact, it very frequently happens that the limit is not reached before the solution is saturated. With sodium chloride the critical concentration is about 5 per cent., whilst in strong brine, although corrosion is not zero, it is far less rapid than in pure water—a fact well known to marine engineers. In the case of some salts, notably the alkaline chromates, the critical and limit concentrations are very small. Such substances are therefore typical inhibitors, and are often used in boiler water as such.

Of more practical interest are solutions containing more than one salt, especially when we have stimulators and inhibitors together. In such cases the greater the amount of stimulator present in the water, provided its critical concentration is not exceeded, the more of the inhibitor will have to be added to stop corrosion. It is in such cases, probably on account of the increased electrical conductivity of the water, that pitting is very likely to occur, for, as will be shown later, this is almost certainly associated with electrolytic action. The action of salts is very fully considered in Friend's book, to which reference has already been made.

It is perhaps worth while to apply the foregoing results to the special case of the Goldfields water main, which has corroded badly, chiefly owing to the presence of chlorine ion and magnesium ion, together, in the water. As is well known, the problem was submitted to a committee of engineers and chemists in London, including the late Sir William Ramsay, and this committee recommended the reduction of the oxygen concentration as far as possible by de-aeration, but, as de-

aeration cannot be complete in practice, and as magnesium chloride is present, which will attack iron slowly even in absence of air, they suggested the addition of a small amount of lime as well. Outside, the pipe was to be treated with solid lime, which, as experience with reinforced concrete shows, is sufficiently concentrated to protect the iron in the presence of air and chlorides.

EFFECT OF THE STRUCTURE AND COMPOSITION OF THE METAL.

The physical state of the metal is of importance, as want of homogeneity stimulates. Even the purest metals, however, are not homogeneous if crystalline, the crystals being apparently cemented together by thin layers of amorphous (non-crystalline) metal which is more susceptible to attack. In such cases corrosion is seen to follow the crystal boundaries. The coarser the structure of the metal, the greater will usually be the rate of attack. Thus, Whyte (Transactions, Faraday Society, *loc. cit.*) cites the case of the marked corrosion of a section of mild steel water main as compared with the remaining sections. Chemical analysis showed no difference in composition, but an examination of the micro-structure revealed a very coarse structure with large crystals of fierite segregated from the pearlite in the faulty section, showing that the metal had been badly burnt during manufacture.

As is well known, contact with a chemically less active metal is a frequent stimulus to corrosion. This is usually referred somewhat vaguely to "galvanic action," but it is only in the special case of the dissolving of a metal, such as zinc, in acid that the mechanism is at all understood. It is found that metals differ greatly in the ease with which hydrogen gas can be evolved from their surface, although the chemical action may remain the same. Zinc, lead and mercury offer a relatively greater resistance, whilst platinum and iron offer hardly any resistance at all. Hence, pure zinc, in spite of its great chemical activity, dissolves only slowly in acid, but, if it be connected with a piece of iron or platinum immersed in the same solution, vigorous action ensues, zinc passing into solution to form zinc ions, and an equivalent amount of hydrogen ions being pushed out of solution on to the other metal and then discharged, forming gaseous hydrogen. In such cases an electric current flows from one metal to the other, whence the name "galvanic action." On the other hand, connecting the zinc with lead or mercury will produce no effect. Increased corrosion, due to want of uniformity in a metal, may be due to a similar action, one portion being attacked, whilst hydrogen either is liberated or combines with oxygen from the air on a neighboring portion. At the same time, an electric current will flow from one portion to another through the metal and back again through the solution. The stimulating

action of small amounts of salts may be largely due to increased conductivity of the solution.

An interesting case of galvanic action of a different kind was recently brought to my notice by Mr. T. N. Kirton, of the Government Analyst's Department. For the protection of a magazine against lightning, a triangular system of conductors on the roof was connected to three copper plates buried in the ground, and spaced symmetrically about 35 feet apart. The composition of the copper and the nature of the ground appeared to be uniform, yet one of the plates had corroded badly, whilst the others had not. On examination it was found that a downspout from the roof had been arranged to discharge over the plate which had corroded, in order to improve the electrical contact with the ground. This of itself would not have mattered, but the roof had been painted with a mixture of lime and salt, so that this particular plate was in contact with a stronger solution of salt than the others, thus increasing its tendency to be converted into basic chloride. In fact, the very perfection of the electrical connections was the cause of the trouble. Had the plates been connected to separate conductors, this "concentration cell" would not have been set up.

A special form of disintegration is sometimes found in pure metals as well as alloys, which, although it is not strictly corrosion, should be mentioned. Most metals, even when slowly cooled, are left in a condition which is stable only at higher temperatures, and in consequence thus have a tendency to change into another (usually crystalline) form, which is more stable at ordinary temperatures. A change from one crystalline form to another will cause the metal to crumble to a mass of loose crystals, frequently without change in composition. Fortunately, such change is excessively slow under ordinary conditions, otherwise no metal structures would be possible. But under special conditions, such as continued vibration or contact with solution of salts of the metal, the change may be stimulated. The failure of tanks and other vessels of lead is sometimes due to this cause. The presence of soluble sulphates or other substances which will prevent the presence in solution of soluble lead salts will usually hinder the change. Tin shows a sharp transition point at 18° C., the stable form below that temperature being a loose grey crystalline powder. By exposure to long continued cold, as in a European or Canadian winter, complete change to the grey form frequently results, with consequent destruction of the original article. On remelting the tin is restored to the compact white form without change in weight.

Lead, of course, shows ordinary corrosion as well, being rapidly attacked by water containing carbonic acid and oxygen

in solution. Small quantities of alkaline salts such as sodium carbonate and nitrate have a strong inhibiting effect. Soft peaty waters attack lead. Hard waters usually do not.

The influence of the composition of metals on their corrodibility has been extensively studied, especially in the case of iron and steel. Corrodibility seems to increase with addition of carbon up to about 1 per cent., and then to decrease. Percentage of carbon has, however, much less influence than the heat treatment which the metal has received. Thus in the case of a tool steel, the hardened steel (Martensite) and the completely softened metal (Pearlite structure) were found to be relatively stable, whilst steels which had been heated to intermediate tempering temperatures were more rapidly corroded, a maximum being reached with metal tempered at 400° C. (Osmondite). There is little to choose between steel and soft iron, corrodibility being influenced largely by the mechanical and heat treatment of the metal.

Nickel steels resist corrosion, but when corrosion has once started it is said to go on rapidly. Evidence on this point is, however, conflicting. Chromium markedly reduces corrodibility. A chromium steel containing about 12 per cent. of chromium, 0.3 per cent. of carbon, 0.5 per cent. of cobalt, and a little silica and manganese, has been put on the market by Thos. Firth and Sons, of Sheffield, under the name of "stainless steel." It is not attacked by salt solutions, fruit juices, vinegar, etc.

The presence of sulphur, especially in the form of manganese sulphide, greatly stimulates the corrosion of iron and steel, the sulphur readily oxidising to sulphuric acid in presence of air and water. Pitting is very apt to occur in such metals, owing to the particles of manganese sulphide present in the metal. Ferro silicon alloys, on the other hand, containing 15 to 20 per cent. of silica, are remarkably resistant to corrosion, but unfortunately they are brittle and difficult to machine. They are used, however, for chemical purposes.

The corrosion of brass shows some points of interest. Brasses containing up to about 37 per cent. of zinc consist of a homogeneous solid solution, whilst those containing up to about 45 per cent. of zinc (Muntz Metal) consist of crystals of two solid solutions side by side. As might be expected, Muntz metal is more easily attacked by acids or by electrolysis than ordinary brass, but, rather curiously, is less attacked by sea water. The initial corrosion of brass and Muntz metal consists in complete removal of zinc crystal by crystal, there being a sharp boundary between the residual copper and the unacted-on metal. At a later stage the copper also will be attacked. The addition of 1 per cent. of tin or 2 per cent. of lead has been found to make brass more resistant to corrosion,

probably by the formation of a continuous film of lead or tin oxide. Smaller quantities of these metals, however, are worse than useless.

Protective Coverings.

These can be discussed only very briefly here. A fairly full treatment will be found in Cushman and Gardner's book.

Linseed oil varnishes and japans are not satisfactory coatings for iron and steel. Not only are they usually porous after drying, but they absorb free hydrogen, and therefore actually stimulate corrosion. The addition of suitable pigments, however, makes a good protection, but again many pigments are stimulators. Pigments which conduct electricity, such as graphite, or those which are fairly soluble in water, such as gypsum, should be avoided. Lead and zinc paints are usually good, zinc chromate being one of the best inhibitors known. A pigment which has given great satisfaction in Admiralty practice is zinc dust, as it absorbs oxygen, and the resulting zinc oxide is itself an inhibitor. On the whole, linseed oil seems to be a satisfactory vehicle, but is improved by the addition of copal varnish. Natural bitumens are good protectors, but become brittle on exposure to light. Artificial bitumens made from tar are better in this respect, and are improved by admixture with lime, which neutralises acids and other corrosive substances. Galvanising is an efficient protection if uniform and thick enough, but frequently this is not the case. Thin galvanising corrodes rapidly. Tin and copper, being electro-negative to iron, stimulate corrosion if the iron is exposed, and, unfortunately, it is difficult to produce a coating of tin which is free from pin holes.

It will be seen that the subject of corrosion is very large, and only the fringe of it has been touched in this paper.

END OF VOLUME VIIa.

Western Australian Institution of Engineers.

(INCORPORATED)

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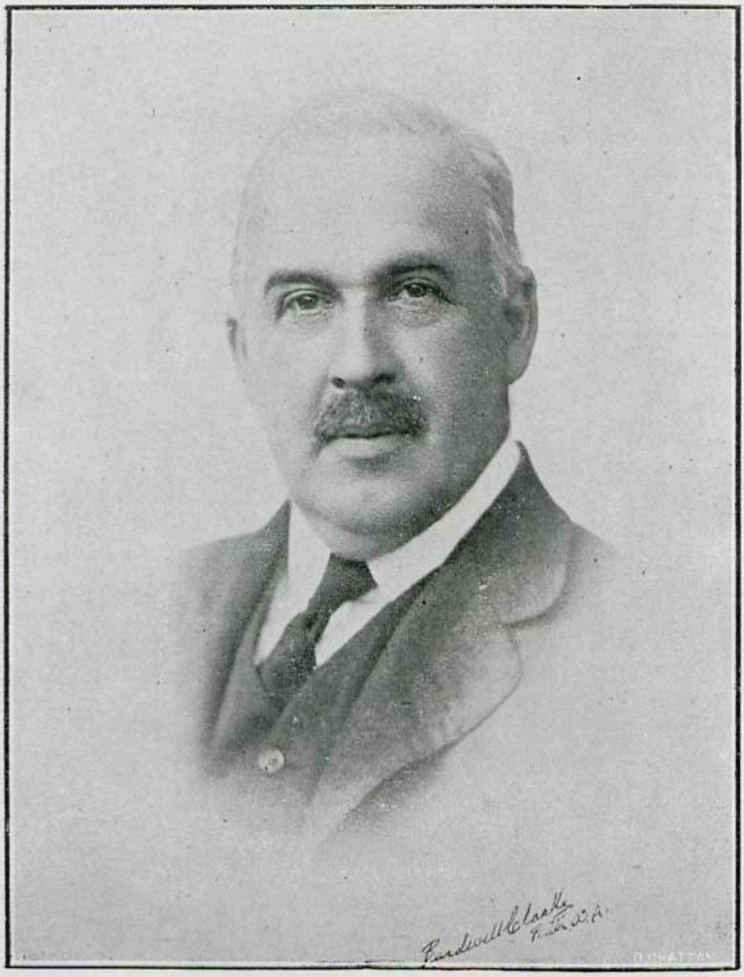

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PROCEEDINGS—WESTERN AUSTRALIAN INSTITUTION OF ENGINEERS.
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GENERAL MEETING HELD AT THE INSTITUTION'S ROOMS, PERTH, ON APRIL 4, 1917.

PRESIDENTIAL ADDRESS.

BY WILLIAM J. HANCOCK.

In accepting the office of President of this Institution, I beg to tender to you my thanks for the high honour you have conferred upon me. It is an honour I much appreciate. I fully realise that it carries with it responsibilities, and I trust, with your assistance and consideration, I shall be able to maintain the office of President on the high level of my predecessors. At this time, when our thoughts are concentrated on the terrible struggle raging in Europe and on the high seas, we hear but the echo which warns us to prepare for all events and to relax no efforts to help to defeat a powerful and ruthless foe, and we honour those men and fellow members of this Institution who have answered the call of our country.

To engineers the war has a special interest, since it is a war in which the engineer and the chemist have taken so prominent a part. Is it not a reproach to civilisation that the forces of science, engineering and chemistry, are being used to the uttermost to destroy the works of industry and art, which in time of peace they had assisted so much to build up? And the civilisation upon which we so much pride ourselves appears, after all, to be but a veneer, to disappear with the first explosion of war.

The first duty of a President of this Institution is to read an address at the beginning of his official career. I have, therefore, chosen for my subject this evening a brief review

of electrical progress in this State. When I began to compose my address, I soon realised that it would be impossible to go into much detail in the short time at my disposal, and it became a question of condensation, rather than expansion, of historical data. I feel sure that there are many members of the Institution who would be well able to supply interesting data of early engineering works, and I would appeal to members not to let the interesting history of engineering of early days in this State be lost.

Telegraphs.

The earliest electrical engineering in the State, as in most countries, was in connection with electric telegraphs. The first telegraph line was constructed in 1869, from Perth to Fremantle, by the private enterprise of Mr. Edmund Stirling. The first pole of this line was erected on 9th February, 1869, near the then William Street jetty, and the line was opened for traffic on the 31st June of the same year.

Owing to the success of this enterprise, the Electro-Telegraph Company was formed in the following year, to erect telegraph lines to other towns, and the first pole of this company's lines to Guildford, York and Northam was erected in St. George's Terrace by Governor Weld on 13th February, 1871. All these lines were subsequently acquired by the Government.

The telegraph line to Albany was built by the Government and opened on the 21st December, 1872.

The first pole of the intercolonial line to Eucla was erected at Albany by the Governor on 1st January, 1875, and the line was completed to Eucla, 1,006 miles, on 8th December, 1875, and the next day telegraphic communication was completed between Perth and Adelaide, over the new South Australian line.

The telegraph was extended north to Geraldton in 1874, and over the sandy and waterless country along Shark's Bay to Carnarvon, Onslow and Roebourne, in 1885, and in the same year contracts were let with Messrs. Latimer, Clerk and Muirhead and Co., a well-known firm of telegraph engineers, to construct the line from Roebourne to Broome and Derby. With the discovery of gold in the Kimberley district, the line was pushed on to Hall's Creek and to Wyndham, the most northern town (2,102 miles) from Perth, where the telegraph office was opened in January, 1893, over 24 years ago, and by way of interesting comparison, Wyndham is a slightly greater distance from Perth than Constantinople is from London.

In the South-West direction, the telegraph lines were extended to Bunbury and Busselton in 1871, and when the

lighthouse was built at Cape Leeuwin this station became the most southern point, 228 miles from Perth. The telegraph to Kalgoorlie, Cue and Marble Bar was opened in 1894.

The early telegraph lines were constructed of sawn wooden poles, with Siemen's iron hooded insulators and galvanised iron wire of No. 8 gauge. On the line north of Geraldton, on account of the termites, or white ants, iron tubular poles were adopted. There was little or no settlement in the early days, and the telegraph stations were many miles apart. In many of those long desolate sections water was unobtainable, and, for the use of the linemen, special iron tanks were erected at sometimes 20 to 30 miles apart, and in these sections, inhabited only by the natives, the linemen often ran great risks in performing their duties. Sometimes after a weary journey over hot sand the lineman, with his horse and cart, would arrive at a tank, only to find that the natives had driven a hole into the bottom to obtain a drink, and then let the rest of the water run out into the sand. In other portions of the North-West line in the rainy seasons the river might come down a banker and spread over the country for miles, sweeping away the iron poles and wire, and great credit is due to the hardy telegraph lineman, who had to go out at any time and in any weather on his lonely inspection to repair a broken pole or wire and restore communication. The type of instrument used throughout the telegraph service of the State was the ordinary Morse sounder, and on some busier circuits, duplex and quadruplex were adopted. With the great increase of traffic as a result of the discovery of gold in the Coolgardie district, Wheatstone automatic instruments were obtained. Owing to the heavy traffic with the Eastern States, and the occasional breakdown and trouble with the insulation for high-speed work along the coast to Eucla, a new line better insulated and equipped was built further inland, starting from Dundas, *via* Balladona to Eucla.

During the period I was Superintendent of Telegraphs, I obtained authority to reinsulate several of the main lines with a higher class of insulator, and ultimately the old iron hooded insulator disappeared altogether.

In some places hard drawn copper wire, 200 lbs. per mile, has been used along the railway sections not affected by bush fires.

A telegraph circuit such as that from Wyndham to Eucla, partly inland in the tropics, and over long stretches of dry sand plains, to the more temperate south, and eastward along the cliffs of the Australian Bight, presents a unique variety of conditions. On the long section, over sand plains, during a spell of very dry hot weather, the electrostatic state of the

line frequently renders it impossible to operate without a partial earthing at both ends. While on the Eucla section, where the telegraph line runs for many miles along the cliff close to the sea, and subject to the heavy salt-laden breezes from the Southern Ocean, efficient insulation was often difficult to maintain.

As an instance of the use of a long telegraph circuit in determining longitude, and as the distance is probably the longest on record, it may be interesting to refer to experiments carried out in 1890. The H.M.S. *Penguin* was engaged in carrying out marine surveys of the North-West coast, and Captain Osborne Moore was anxious to accurately determine the longitude of Broome (Roebuck Bay). In consultation with Sir Charles Todd, of the South Australian Telegraphs, we made the necessary arrangements on the Western Australian section for accurate automatic repeating from the Adelaide Observatory to Broome. On 30th October, 1890, at noon, all traffic was stopped and the clock beats of the sidereal clock at Adelaide Observatory were sent over the wire along the shore of the Bight, *via* Perth, to Broome, where Captain Moore was able to compare the clock beats with his chronometers. The total distance was 3,567 miles, 2,486 miles being in Western Australia, and 1,075 miles in South Australia.

The retardation due to the instruments, being about .38 seconds, and the velocity of electric transmission being taken about 16,000 to 18,000 miles per second over the iron wire from Adelaide to Broome.

Similar tests were made between Adelaide and Fremantle and Albany. All the tests were very satisfactory, and we received the thanks of the Hydrographic Department of the Admiralty.

The telegraph system of the State, which began in 1869 with two stations and twelve miles of single line, and gradually developed to 167 stations, 6,111 miles of pole line and 9,104 miles of wire up to 1901, when the telegraphs and telephones were taken over by the Federal Government. At the end of last year, the total number of miles of pole line reached 8,791 miles and 16,728 miles of wire, and I think it is greatly to the credit of the State that the more difficult and greater part of the telegraph lines were built by the State, for the wire stretched from Eucla to Wyndham, a distance of 3,131 miles, as far back at 1893.

Shortly after the telegraph line had been erected between Derby and Hall's Creek, much trouble was caused by the constant smashing of the insulators by the natives, descendants of the Stone Age man, and who still used the stone spear heads and axes.

With the advent of the telegraph, the porcelain insulator offered a new and attractive substitute, and the uniform material and manufacture was as much appreciated by the native as by the telegraph engineer. The natives climbed the poles, and then with their stone axes smashed away the insulator, and from the broken pieces made excellent spear heads with the wonderfully accurate serrated edges. The Cordeaux insulator was a convenient shape, and the natives soon learned to break the insulators to the best advantage, and not a few gold seekers and more than one of the telegraph linemen have been killed by the native spears. When I was in Derby some natives had been caught by the police breaking the insulators, and I induced the natives to make some spear heads before me, and it was most interesting to watch the native, with his primitive methods, convert a modern telegraph insulator into what might be called a prehistoric weapon.

While the problem of protecting the insulators from the natives was still unsettled, relief came from an unexpected quarter. The rush to the new Kimberley Goldfields brought with it new material in the shape of whisky and gin bottles, and as these emblems of civilisation were strewn about freely along the path to Hall's Creek, and were easier to obtain than by climbing poles, the telegraph insulator soon became unfashionable, much to the advantage of the telegraph service.

I might mention as an interesting comparison of native ideas that while our North-West natives only used the porcelain insulators, the natives of North Queensland cut down the iron wire for their spears, and leave the insulators alone. Ethnologists might look on this difference in native customs as an advance from the Stone to the Iron Age, but neither custom was much appreciated by the telegraph engineer.

Honour is due to the telegraph engineering staff and surveyors of the pioneer days, who carried the telegraph line through many a mile of unknown country, in face of unknown dangers, and their work is worthy of record in an Institution of Engineers.

Telephones.

I had the honour of installing the first telephone exchange system in the State, in 1887. The original exchange building consisted of a small cottage in Wellington Street, near the railway bridge, and facing Barrack Street. In one room were erected two switchboards of Western Electric make, of the shutter and plug cord type, the capacity for each board being fifty subscribers. The other rooms were used as office and stores, while the kitchen made a very convenient instrument workshop, and a good yard offered excellent accommodation for stacking poles and construction material.

The exchange was opened on the 1st December, 1887, with seventeen subscribers, the charge being £12 per annum, and was open from 8 a.m. to 6 p.m. The telephone system soon increased, and after four months' working reached fifty subscribers, and then we opened the exchange day and night.

The original instruments were of the magneto type, and this system was used up to the introduction of the automatic system in 1914.

The outside construction work consisted of jarrah poles 35 ft. long, square tapered, with tuart cross arms. Cordeaux insulators and hard drawn copper wire of 200 lbs. per mile. Many of the white painted and heavily laden poles have been familiar objects in the streets of Perth and Fremantle until a few years ago, when they were removed to give way to a better system of underground cables.

With the growth of the telephone system, the cottage in Wellington Street soon became too small, and in 1890 new switchboards were installed on the top floor of the General Post Office, and the system diverted to the new exchange. In course of time, this exchange gave way to the new automatic system, which was installed in the new Telephone Exchange Building in Murray Street in 1914.

Simultaneously with the opening of the first exchange in Perth, four trunk lines were erected to Fremantle, and the first exchange in Fremantle was opened with nine subscribers in a small room at the back of the Town Hall. Soon afterwards this was shifted to the new Post Office Buildings, near the railway station. The new exchange at Fremantle is of the type known as the central battery system. When the subscriber takes the receiver off the hook, a small electric lamp lights up in the exchange, and, except for the lamp, instead of the drop shutter and certain other improvements, it is a reversion to one of the oldest exchange systems.

The telephone service has increased from one exchange with seventeen subscribers in 1887 to the following at the end of last year:—

Exchanges	105	
Instruments	10,852	
Exchange lines (metallic)	6,620	miles
Underground conduits	52	,,

In the early days the railway telephones were maintained by the Telephone Exchange under the Department of Works and Railways, and before the electric interlocking system was introduced the traffic was controlled by telephones and staff system, the telephone instruments being connected in series, and station called by code signals. I realised that this arrange-

ment was unsatisfactory, and that the railway should have a special and responsible officer to maintain their telephone system, and the present Railway Electrical Engineer, who has held the position ever since, brought the system up to the high state of efficiency to which it has attained.

SUBMARINE CABLES.

Only brief mention may be made of submarine cables. Incidentally I may state that the first piece of work I had to do on my arrival in this State was to examine the old telegraph cable to Breaksea Island, outside King George's Sound, and, finding it beyond repair, a new cable was indented and laid, a work which afforded considerable excitement, risky at times, in the uncertain and frequent rough weather about Breaksea. A submarine cable to Rottnest was laid in 1901, and this completes the list of local submarine cables. As to the telegraphic cables connecting Western Australia with the rest of the world, although not strictly within the purview of this paper, it may be of interest to allude to them. The first ocean submarine cable to be landed on the shore of Western Australia was in 1881, when the Eastern Extension Telegraph Co. laid a cable between Banjoewangie, Java, to Broome, thus providing a through route from Perth to Europe *via* Java. And in 1901 the Company laid another cable from Cottesloe Beach to Cocos Island, Mauritius, and thence to Durban, giving an alternative route *via* East or West Coasts of Africa to Europe. In the next year a cable was laid across the Pacific *via* New Zealand, Fiji, Fanning Island, to Vancouver, in 1902.

RADIO TELEGRAPHY.

In 1902 we fitted up a small experimental wireless apparatus, and by the courtesy of the Lodge-Muirhead Company, obtained the loan of one of their syphon recorder wireless apparatus, which could be adjusted to extreme sensitive and short wave lengths.

Under the Wireless Telegraph Act, 1904, the P.M.G. had the exclusive privilege of radio-telegraphy in Australia, and granted licenses for private installations. In 1915 the administration of the Act was transferred to the Naval Department.

In October, 1909, tenders were called for two high power stations, one on each side of Australia—namely, at Sydney and Perth (Applecross). The Applecross station is a fairly high power station, and the buildings were erected by the Public Works Department of this State, and apparatus installed by the Australian Wireless Telegraph Company. It would not be proper at this time to give any description of this station. A station on similar lines has been erected near Sydney. I may

mention that communication can be held with Cocos, and at night, under favourable conditions, Colombo and far off Fiji can be heard sending out signals into space.

The Applecross station can instantly alter the wave length of its signals from the Commercial wave length of 600 metres to the Navy wave length, so that the ordinary merchant vessel systems do not interfere with ships of war. At the outbreak of war it was deemed advisable to establish an auxiliary wireless station for shipping. In conjunction with the Military Department, our new x-ray plant of 4 kilowatts was easily converted into an efficient wireless installation.

Owing to the insular position of Australia, it was realised that a chain of wireless stations was required around the entire coast-line of Australia, and to create an effective system two main factors had to be considered:—First, that the stations should be at a distance apart so that each station could communicate with the next and the station beyond it, in case of breakdown. Secondly, that the distance apart of the stations should be governed to a great extent by the normal working range of ocean-going vessels. With these objectives in view, twenty-one radio-telegraph low-power stations have been erected around Australia and are now in operation at the following points:—Sydney, Flinders Island, Melbourne, Hobart, King Island, Mt. Gambier, Adelaide, Esperance, Perth (Applecross), Geraldton, Broome, Roebourne, Wyndham, Port Moresby, Wood Lark Island, Thursday Island, Cookstown, Townsville, Rockhampton, and Brisbane.

The low-power stations have a range of 500 miles in day time and, under favourable conditions, up to 1,500 miles at night. The high-power stations at Applecross and at Sydney each have a range of 1,250 miles in the daytime and of 2,000 miles at night, this being the normal sending range. The Sydney station can, therefore, keep up communication with New Zealand day or night.

Electric Lighting.

The first attempt of public electric supply was made in 1888, when a small electric plant was installed in an old building next to the Criterion Hotel, in Hay Street, or rather in Howick Street, as that portion of the thoroughfare was then named. The plant consisted of a 40 h.p. portable engine with a 15 K.W. Elwell Parker dynamo, and the hotel was the first building in Perth to be wired for electric lighting. Before the lighting station was in working order, it happened that a ball was to be given at Government House, and as a novelty, His Excellency was anxious to have the ballroom lit up by electricity, and he consulted me on the matter. I arranged with the manager of the new electric light company to supply the current. As

the cable available was not quite sufficient to complete the distance, and as there were no firms from whom we could obtain electrical supplies, the deficiency was met by the use of some telegraph wires on temporary poles, from Hay Street down to Pier Street, and across St. George's Terrace to the old ballroom. The lamps of the first supply were 60 volt, 8 candlepower, with platinum loop connections, costing 6s. 6d. each, and we were able to produce a fairly satisfactory effect so long as the steam pressure was kept up. The guests at the ball were occasionally able to judge of the illuminating effect from a glow of red hair pins to that of a somewhat dazzling brilliancy. As the switchboard instruments had not arrived, control had to be arranged by means of a special telephone between Government House and the power station.

The illumination at Government House on this occasion was about the maximum capacity of the plant. At all events, the first electric lighting was a success and greatly admired. After this success, the Government decided to instal electric light in the Legislative Council Chambers, in Hay Street (now the State Savings Bank). The installation was carried out in wood casing, and the fittings and wiring were of excellent quality. I have no hesitation in saying that the switches and fittings were far and away better in material and workmanship than the usual class of fitting to be obtained in Perth to-day. In new buildings at this period gas was always installed in addition to the electric light, as a stand-by, as the public were not certain of the continuity of the electric lighting after a few experiences of being left in the dark.

After a short life, the Electric Light Company came to an untimely end, due to competition from the Perth Gas Company, who had obtained powers to add electricity to their gas monopoly, which they possessed for a radius of five miles from the Perth Post Office.

The Gas Company erected an electricity supply station, with steam plant and accumulators, next the gas works, in Wellington Street. Subsequently they purchased land on the opposite side of the street, and erected an electric supply station, which grew until there was no more space, and an auxiliary station was opened near the West Perth railway station.

For some years the electricity supply of Perth was at 110 volts, until about 1899, when the system was changed to the three-wire system, 440 volts for power and 220 volts for lighting.

In 1913 the City Council purchased the plant and rights of the Perth Gas Company, and continued the supply from the two stations.

Another change is near at hand, and preparations are approaching completion for the change of the city supply from direct current system to alternating current, when the lighting and power supply will be obtained from the four City transformer sub-stations, where the high tension 6,600-volt current from the new East Perth power house will be transformed to low pressure, 40 cycles—250 volts single phase for lighting, and 440 volts three phase for power. When this change is effected, the generating stations in Wellington Street and West Perth will be shut down.

Government Scheme.—The new East Perth power house, which is now almost completed, has been designed and constructed by Messrs. Mertz and McLellan, consulting engineers for the Government, and is of modern design, and is now partly in operation. The effect of this large economical central supply of electricity in our community will be far-reaching. Already the supply mains from the station stretch out to Guildford and Midland Junction and deliver current to the sub-stations at 20,000 volts. The transmission lines for 20,000 volts are almost completed to Fremantle, where the existing power house will in course of time be shut down and the electric supply taken from East Perth. It is but a question of time when the supply mains now erected on the south side of the river will be supplemented by supply mains on the north side of the river, forming a girdle of electric supply, and suburban municipalities such as Subiaco, Claremont and South Perth will close down their power houses and become linked up by small sub-stations erected at the most economical points of supply, and the supply of electric power and light in the metropolitan area will thus cease to be a local municipal affair, and will become a State supply, similar to the water supply and sewerage throughout the metropolitan-suburban area.

It cannot be expected that these economical results can be obtained without considerable outlay. The change of supply to Perth involves the replacement of all direct current motors, fans and lamps of 220 volts for lighting and 440 volts direct current to 250 volts for lighting and 440 volts, three phase, 40 cycles, for power. The estimated cost to the City of Perth will not be less than £200,000. The cost of the change involved at Fremantle will not be so heavy, but it necessitates the alteration of the existing system of 50 cycles, 440 volts, two-phase, to 40 cycles, 400 volts, three-phase, for power, and from 220 volts to 250 volts for lighting.

It is expected that as the result of this change of supply, a general reduction of the price per unit will be effected.

The responsibility for the adoption of alternating current for the City of Perth, as well as the adoption of 40 cycles, rests

entirely with the consulting engineers, Messrs. Mertz and McLellan.

In my opinion, it would have been better to have continued the existing direct current supply in the City and suburbs, and thus saved the City the great cost of altering or converting cables, motors, lifts, fans and lighting throughout the City and suburbs so as to suit the new alternating current supply, and, instead of static transformers, synchronous motor generators would be installed to effect the conversion to direct current.

With regard to the periodicity of 40 cycles: While this has an advantage for large motors, in that motors can operate at 20 per cent. lower speed than similar motors on 50 cycles, this advantage is outweighed by the fact that 40 cycles is neither British nor American standard practice, the former being 50 cycles, and the latter 60 cycles; and as Sydney and Melbourne have adopted 50 cycles for bulk supply, we shall be somewhat handicapped in obtaining 40 cycles motors and appliances in the future.

The Naval Base will also be temporarily supplied with current from East Perth for its construction work, although when the Naval works are completed they will no doubt have their own power house, so as to be independent of outside supply, and direct current will probably be adopted, in accordance with the system prevailing in the Navy.

In the country districts electric lighting installations started at a comparatively early date, and for many years the number of towns with an electricity supply system in this State exceeded any other State in the Commonwealth.

The first town outside Perth to establish an electricity supply station was Coolgardie, in 1898, and to-day the total number of towns providing a public electric supply is 31. Of this number, 22 towns have their own supply system, and eight stations are privately owned.

Of the 31 towns, 14 stations are operated by steam, 12 by producer gas plants (of which six used wood and two charcoal, while three use both wood and charcoal), and six towns purchase current in bulk. Twenty-nine towns have adopted direct current on 220 volts for lighting, while the Kalgoorlie Power Company and Fremantle have alternating current plants. The 110 voltage has disappeared, excepting in a few private installations.

Electric Tramways.

The first electric tramway was opened in Perth in 1899 by the Perth Electric Tramways, Limited, under a concession from the City Council, and soon extended to the suburbs, the total miles being 22½ at the time of purchase by the Government

in 1913. The power house was erected near the East Perth railway station.

As the result of the partial opening of the Government alternating current scheme, the tramway service of 500 volts direct current is now being obtained by rotary convertors, and the tramway generating station closed down.

The Kalgoorlie tramways were opened in 1902, and extended to Boulder, the total length of track being 19½ miles. The Kalgoorlie Electric Power Co. supply the current.

The Fremantle Municipal Tramways was opened in 1905, and has its own power house.

The Leonora Municipality have a single track of three miles to Gwalia, opened in 1908.

The gauge of all tramways in the State is 3 ft. 6 in.

Some time after the Perth tramways had been in operation, trouble was experienced with corrosion of the water and gas pipes. This was mainly due to insufficient bonding of the rails and the pipes being too close to the track; and in conjunction with the manager of the tramways, we carried out some experiments, and obtained interesting data as to the electric potential zones of Perth, and, as a result, we insisted on better bonding of the rails and track, and I also recommended that no gas or water pipes should be nearer than 24 inches to any part of the tramway track, and this latter regulation was made one of the conditions of provisional orders in subsequent tramway Acts. Similar tests were also made in conjunction with the Goldfields Water Supply Department, as to observation and protection of water mains of the Coolgardie Water Scheme, and some very interesting data was obtained. The point where the corrosion of the underground pipes was most severe and difficult to deal with was near the power house. No doubt the adoption of the Thermit welding will tend to improve the conductivity of the track, and reduce electrolytic effects.

In 1904 the question of the electrical equipment of Fremantle harbour was decided, and I strongly recommended that the harbour cranes and equipment be at 440 volts, 3 phase, 50 cycles, instead of the 2 phase system adopted by the town of Fremantle. A contract was made by the Harbour Trust to obtain electricity supply at four harbour sub-stations, when the town supply of 2,200 volts, 2 phase, was transformed to 440 volts, 3 phase, 50 cycles.

In 1905, five 3-ton and one 10-ton Gantry cranes were ordered, and I inspected these for the Department at the contractors' works, Glasgow, and when they arrived in the State they were erected under my charge on the Fremantle wharf, and placed in commission, two on the north side and four on the Victoria Quay. These were supplemented in 1913

by four similar 3-ton cranes, making a total of nine 3-ton and one 10-ton cranes. Subsequently three railway track electric cranes were obtained, and the grain shed elevators and wharf wheat loaders are all electrically operated.

In 1912, two 3-ton electric Gantry cranes were erected at Bunbury Harbour by the contractors, Messrs. Arrol and Co., Glasgow. In these cranes I had incorporated some alterations and improvements, from our experience with the Fremantle cranes, to suit the local conditions at Bunbury.

When the Government railway workshops were erected at Midland Junction in 1905, a complete electrical installation for operating the workshops was installed, at 220 volts, 3 phase, 50 cycles.

Electric Transmission.

Shortly after the discovery of gold at Coolgardie, the necessity of a plentiful supply of fuel and water became apparent, and a syndicate was formed about 1892 to erect a transmission line from Northam (285 miles distant), the nearest locality with a good water supply for the steam plant. This matter was referred to Lord Kelvin, but owing to the Government deciding to construct the Coolgardie Water Scheme, the selection of Northam as the generating point was greatly modifield, and the scheme fell through. Subsequently two schemes were proposed, but neither got beyond the initial stages. Both were to transmit energy from Collie to Kalgoorlie, one along the railway route, and the other on a larger scale, across country, from Collie to Kalgoorlie. The latter scheme was to consist of two 3-phase lines built on steel towers, the line being erected on a fenced strip of land, with patrol stations at intervals. As I was in London at the time that the scheme was being considered, I had several discussions with the people interested in the matter, and the engineers connected with the Victoria Falls power scheme, and on the Continent I had the opportunity of inspecting several of the hydro-electric systems, both completed and in course of erection. A very interesting hydro-electric plant I saw near the town of Goritza, near the Austro-Italian frontier, the scene of much recent fighting.

The Goldfields transmission proposal involved twice the voltage and twice the mileage of any scheme existing at the time, twelve years ago. Indeed, the only other scheme at the time comparable and actually exceeding the Collie-Kalgoorlie proposal was the Victoria Falls transmission scheme of 700 miles to Johannesburg. In this case the supply was unlimited, and a greater head of water than at Niagara Falls.

Both these great schemes fell through for practically the same reasons—the liability of an interruption on the very long transmission line through exposed and uninhabited country,

either by some accident or design, without a moment's warning: and secondly, the mines, being so far away from the generating point, were not in touch, and control, labour or other questions might arise, especially as the conditions at both ends of the line differed so much, and interest and sinking funds on the heavy cost of the transmission line and upkeep would add considerably to the cost per unit.

Unfortunately, Western Australia possesses no water power. excepting the tidal waters of the far North coast, where the great inward and outward currents due to the 40 to 50 ft. tides offer a possible source of energy for industries in the northern part of the Continent—a floating power station moored in the channel where the energy of the tidal current could be converted by paddle or screw and suitable machinery into electric energy for distribution. But I fear until the demand arises this source of electrical energy is outside practical engineering for some time to come.

The direct solar heat, of which Australia receives such a bountiful supply, may also some day be used as a source of energy under special circumstances.

At present our only source of energy is coal and timber, and this narrows down the advantage of electrical transmission and comes rather to the question of using our coal supply to the best advantage, and the fact that our coal, so far discovered, is better for raising steam than making gas, gives the engineer another factor to surmount.

On the other hand, the improvements and experience of transmission work warrants serious attention to the problem as applying to our State.

The object of an electric transmission scheme is to transmit energy from the place at which it can be most economically generated, to where it can be more effectively used. As a source of energy, water power has great advantages over coal, although in both cases the sun is the source of energy. The sun performs the work of lifting the water by evaporation and depositing it on the mountain side, and the engineer makes use of the fall of the water to the sea to drive the hydraulic machinery, which in turn drives the electric generator, and thus from the sun we have as near to a perpetual supply of energy as we can ever expect.

In coal we have the energy of the sun, stored up in prehistoric times, which cannot be renewed, and it behoves us to consider the problem of the supply of the energy, as the more our industries and railways increase, so much more do we absorb our limited coal supply. Can we transform the coal energy more efficiently at the pit's mouth and transmit it over the wire? Experience in Europe and America has shown that

transmission of energy by wire can be carried out to a great advantage from an economical and practical point of view, and electrical transmission has long passed the experimental stage; but there are other aspects of the subject which the electrical engineer fully realises and has to face, especially with regard to the conditions obtaining in Western Australia.

With improvements in steam boilers, better results can be obtained, but improved boilers can be erected at either end in the form of coal in railway trucks as against the energy sent by wire. In the former case the user can store up his coal energy in his yard and have it under his control for emergencies, subject to deterioration in calorific value, and the interest on the outlay of storing fuel is but the premium on insurance of continuity of supply. In the latter case he has no reserve in the event of interruption on the transmission line, and in time of war or disturbances, when it is imperative that our railways and bridges should be guarded, it should be equally necessary to protect our long transmission lines. These are problems the electrical engineer must face. Indeed, we must look to some vast improvement in the conversion of coal energy into useful effect when we realise that from the heat energy of coal, and under the best modern conditions, we are only able to obtain about 3 per cent. of the coal energy in our electric lamps.

The question of utilisation of our waste timber is a more difficult problem to deal with than that relating to coal, from the engineer's point of view, but the vast amount of stored up energy lying unutilised demands careful consideration, and this matter is being taken up by the Scientific Advisory Board.

Engineering Education.

Having but briefly glanced at the past work and gradual progress of electrical engineering in the State, and having seen the various phases of electrical science slowly but surely develop, it is proper to consider what lessons the past has taught us, and I may be allowed to indicate some points of view that appear to be of interest in regard to the future development of the engineering profession in this State. In the past all our engineers, whether railway, electrical, mechanical, hydraulic and for work connected with harbours, roads and bridges, have been educated or trained either in the Old Country or outside the State. This could only be expected in the early days. Indeed, the native born youth who aspired to be an engineer had to go abroad to obtain knowledge and experience, but the youth of to-day has many advantages over his predecessor, for he has a University of science, literature and art to enter, and also technical schools, and even primary schools giving him first lessons in science.

The doors of the University are open wide to the student

to enter, without fees, so long as he or she pass a qualifying examination which is slightly less difficult than the Leaving Certificate examination of the schools, and in four years of study with three summer terms in the workshops can take out a degree of Bachelor of Engineering.

We have often heard it said that our University has started too soon, and that the State is not ready for it. I have always held the contrary view, that it is a misfortune that the University did not start twenty years ago, for it takes twenty years at least before a student becomes a leading and important factor in the State. It is a matter of the greatest satisfaction to find that this year there are far more students enrolled than in previous years: most of the science classes are doubled or trebled. In Engineering, last year ten students attended; this year 28 have enrolled in this subject, and similar increases are to be observed in other departments. This arises from the fact that the schools, immediately after the University was established, started to teach with the University as the goal in view, and this is the first crop, so to speak, and we may expect that in the future the number of students will increase.

In the University the course of study is a co-ordinate system, and lends itself to a broad knowledge and elevation of the mind, and gives the student a sound basis and ground work on which he can build his future career.

So great is the influx of students that the University is in some difficulty to find accommodation, and the Senate, with the assistance of the Government, is arranging for the necessary increase.

The technical colleges also afford excellent facilities for education, but more for special technical work; and the absence of co-ordination of work is a characteristic difference between the technical schools and the University. Both are valuable and necessary factors in the progress of the State.

The student who has obtained his B.E. degree has the world before him, and on the sure foundation of scientific knowledge gained at the University he must apply several years of practical work and experience of men and material.

After all, there is nothing that can take the place of experience, be it in handling and mastering difficulties, whether they be obstacles found in nature, or in the organisation of work and labour, and modern experience shows that human labour must and should be the first consideration of an engineer. Until such obstacles and difficulties have been met and mastered, and experience gained, no man can rank as a qualified engineer, but even then his education is never complete —there is ever more to learn.

It is during the latter period, after he has left the University, when he has to do his own steering, and when his ballast may not be quite right, when those great institutions of civil, mechanical and electrical engineers appear to be of greatest value to the young engineer. There he can meet others in his own profession and hear their experiences and see the works they have carried out, and I think our own Institution, small as it is, has some responsibilities in this respect, and I feel sure every member will be glad to encourage student members of the Institution to come forward and read papers on special work they may be engaged in.

There is a matter which is difficult to deal with, and that is to get public bodies to recognise the fact that the engineer is best qualified to do engineering work. How often do we find the layman deciding matters he is neither qualified nor trained to deal with, and waste of money and inefficiency are the result, for the layman, from his want of training, never knows when he requires technical advice, and goes on in the hope that he may be right.

Public bodies, such as municipalities and town councils, frequently appoint unqualified men to positions requiring knowledge and experience, and indeed the Government service can show some instances. It is but a few years ago, when a certain suburban municipality called for applications for a Town Clerk and Engineer, with a note after engineer: "Engineering qualifications not necessary." Surely this is the limit! The question of appointing properly qualified and experienced men with proper remuneration to such posts are professional matters that the Institution should deal with and in course of time rectify.

I feel that there is a lack of interest in our Institution at the present time, but all institutions are suffering in the same way, and this is not to be wondered at when our country is at war. We must not be down-hearted, but must go slow for the present, for the work of the engineer will be greater than ever after the war, and then our institutions will flourish again.

(August 1st and 15th, 1917.)

ON THE STUDY OF INFORMATION BY GRAPHICAL METHODS.*

(Abridged.)

By Acting-Professor Alfred Tomlinson.

The advancement in engineering knowledge is due mainly to technology, or applied science, in which graphical study of information is a dominant factor. Engineers are very familiar with the preparation, use and value of dimensioned pictures—sketches and mechanical drawings—of things to be constructed. It is realised that it would be impossible nowadays to carry out work without them. In exactly the same way the engineer of to-day cannot do without the study of data by graphical methods. Amongst other advantages, the graphic diagram presents a picture by which the mind's eye can comprehend, at a glance, the nature of the variation or relationship between variable quantities which are mutually dependent upon one another. By its aid results are readily interpreted which would have a formidable aspect when presented in tabular form. The eye is quick to read and compare differences in size, or shape, or slope, and the mind not being wearied over details of data, is not distracted from the general story told by them.

The value of graphical methods to the engineer cannot be over estimated. Charts or graphs on squared paper, and vector diagrams on plain paper, are all important to the young engineering student, to practical engineers in the works, drawing office, and estimating departments, as well as to the general management in works of construction. The use of squared paper is invaluable to the so-called modernizing and efficiency-improvement engineer, and to the business man, for by its means economy may be effected in all departments, errors and irregular working may be detected, costs and dimensions of manufactures may be reduced to order, to law or formulæ, and a clear light thrown on the entire working of an engineering establishment. A diagram adds a miraculous length to a man's eyesight. The higher the official, the more must his work lie in determining policies, leaving details and mere routine for subordinates to do. Curves show him tendencies and desirabilities, and enable policies to be chosen. If these tendencies are objectionable they can be corrected long before they would have become noticeable in columns of figures.

At the outset it is necessary to distinguish between two kinds of quantities, namely, vector and scalar. Some quantities

* For diagrams see end of paper.

are related to direction in space and cannot be defined without reference to direction, and are called vector quantities, others have no such relation to space and are called scalar. Thus displacement and force are vector quantities, and length and time scalar quantities. Before considering the practical application of graphical studies of information, some of the different methods of graphical charting and plotting will be considered. Scalar quantities may roughly be divided into two groups, illustrative charts and law-computing graphs, while vector quantities are used in computing diagrams only.

Scalar Quantities.

Illustrative Diagrams.—Fig. 1, which illustrates the "bar" method of plotting data, shows very plainly the remarkable effect of water in diminishing the number of fine dust particles breathed per minute by the miner when working. Usually the "bar" method is used where variations are so irregular that a smooth curve would be impossible. Fig. 2 shows the area method of computing data. This is a particular case of what is known as a clock chart. Actually, it illustrates the percentage of excavation work completed some time ago on the Gatun locks.

Law and Computing Graphs.—Fig. 3 shows the common co-ordinate method of using two perpendicular axes for plotting two variable quantities. Points are obtained by projecting from two axes or lines perpendicular to one another. In other words, a points position is known when its distances (perpendicular) from two fixed axes are known. The horizontal measurements are known as abscissæ and the vertical as ordinates. In particular the figure shows the relation, in an alternating current transmission system, between the various quantities—kilowatts, amperes, volts, efficiency and power factor:—Given E.M.F. = 2,000 volts, Line resistance = 2 ohms. Self inductance in line = 5 ohms. Consumer susceptance = 0.05 Mho.

Fig. 4 shows the method of using two perpendicular axes for four variable quantities. Thus a coal containing, by analysis, 80 per cent. carbon, 4 per cent. hydrogen, 10 per cent. oxygen, and some sulphur, has a calorific value of 13,200 B.T.U. per lb. of coal. Fig. 5 shows a special method of plotting three variables. It depends upon the geometrical principle that the sum of the normals from any point in an equilateral triangle upon the sides is constant and equal to the altitude of the triangle. Actually it shows the tensile strength of copper-tin-zinc alloys. The altitude is made to represent 100 per cent. of any of the constituents. Any point of the diagram therefore represents a certain definite mixture of the three constituents. Thus point *A* on the diagram represents an alloy containing 13 per cent. copper, 57 per cent. tin, and 30 per cent. zinc.

When all such points have been plotted and marked with the figures representing the particular property under investigation (tensile strength in this case), lines or contours may be drawn connecting points possessing the property in question to an equal degree. Evidently the strongest alloys contain nearly 60 per cent. copper, 1 to 2 per cent. tin, and nearly 40 per cent. zinc. Fig. 6 shows the polar co-ordinate method of plotting two variable quantities. It depends upon the fact that a points position is fixed when its distance from a pole is known, together with the angle this distance line makes with a given axis through the pole. Actually it shows the distribution of light respectively from continuous current and A.C. arcs, the figures marked on the radial lines indicating candle power in these directions. Fig. 7 shows the ordinary three dimensional method of plotting. Points are obtained by projection from three planes mutually at right angles to one another. These points lie on a surface. The figure shows the surface connecting the breaking strength of cast iron gear teeth with the pitch speed and the arc action. Clearly, a solid may be so moulded as to represent this surface. Fig. 8 shows a cardboard substitute for a solid model. Actually it shows the relation between the efficiency of an eight-foot fan and the area of the outlet opening for various speeds, the area of opening being designated as a percentage of the product of the fan diameter by the width of the periphery. Eight different curves are given for eight different speeds. It is seen that the efficiency is a maximum when the revolutions per minute is about 125 and the area about 29 per cent. The construction of the solid in Fig. 9 is dependent on the geometrical principle that the sum of the normals from any point within an equilateral tetrahedron to the four sides is equal to the normal from a vertex to the opposite side. It is necessary for the sum of the four variable quantities to be a constant, say of 100 per cent. Actually the small shaded solid shows the only portion of the tetrahedron occupied by the field of Portland cement. Fig. 10 shows another type of solid. It is here a necessary condition that for each set of corresponding variables three of them should add up to a constant value, 100 per cent., say. The fourth variable (the height in the model) is unrestricted. The figure actually shows the tensile strength of copper-tin-zinc alloys. It is seen that it is merely a solid representation of the contour tri-axial method, or Fig. 5.

Computing Transversal Diagrams.—Fig. 11 shows charts for addition, subtraction, multiplication and division, and are self-explanatory. Fig. 12 shows another type of multiplication and division chart. It is similar in principle to the left-hand diagram of Fig. 11, the difference being

that the co-ordinate scales are logarithmic, it being remembered that adding logs of numbers is equivalent to multiplying the numbers themselves. Fig. 13 shows a practical application of the principles illustrated in Fig. 11. Actually it is a chart for obtaining the area of steel necessary in reinforced concrete beams. Dotted line indicates the method of using; thus, given effective depth=22 in., breadth=10 in., percentage of reinforcement=0.85, whence A=1.87 sq. inches. Fig. 14 shows a proportional chart, which is based upon the well-known "proportional" property of similar triangles. Actually the chart is for obtaining the outside diameter of a thick pipe, on the Lamé theory, when the inside diameter, the internal pressure, and the safe tensile strength of the material is given. In example, p=internal pressure=4,000 lbs. per sq. inch; f=fiber stress=8,000 lbs. per sq. inch, and d=internal diameter=10 in. Whence, $f+p$=12,000 and, $f-p$=4,000, and from diagrams, by drawing parallel lines, D=17.3 inches. Fig. 15 shows a simple form of alignment chart for addition or subtraction. In the charts hitherto examined the necessary lines or scales were plotted on axes at right angles, or, in the case of the tri-axial method, axes inclined at 60° to one another. This is by no means a necessary condition, and comparatively recently charts having parallel axes have been introduced and developed. They have an enormous advantage over any other type, for they can deal with any number of variables. To illustrate the working in the figure, it is required to add 5 and 8 together. With a straight edge on the 5 mark on the left-hand scale, and also on the 8 mark on the right-hand scale, it is seen that the transversal cuts the centre scale at the 13 mark. It would also be easy to use the chart for subtraction purposes, *i.e.*, 13 on centre scale—5 on left-hand scale=8 on right-hand scale. Fig. 16 shows an alignment chart for multiplication and division. The principle is exactly that of Fig. 15—addition and subtraction. Instead of making the divisions between consecutive numbers equal to one another, as in Fig. 15, the distances between the numbers are made proportional to the logarithms of the numbers, and adding logs of numbers is equivalent to multiplying the numbers together. Example:—5×8, 5 on left-hand scale and 8 on right-hand scale, are joined by a transversal cutting centre scale at 40. All other simple alignment charts are adjusted combinations of charts, Figs. 15 and 16. Fig. 17 shows an alignment chart for obtaining the safe load (distributed or concentrated) on British standard rails when acting as beams. The left-hand scale represents the unsupported span in feet, and the right-hand scale the weight of the B.S. rail lbs. per yard. To obtain the safe distributed or concentrated load, hold a straight edge across the outer scales and read the result on the corresponding central scales.

VECTOR QUANTITIES.

Computing Graphic Diagrams.—Evidently a vector can be represented graphically by a straight line; its magnitude to some scale by the length of the line; its clinure or ort by the clinure of the line; its sense by an arrow-head. Consider the case of a yacht sailing against the wind from a point *A* to a point *B* (Fig. 18), the distance *AB* being 7 miles in a direction due East. Then, when the vessel reaches *B*, there is evidently a sense in which we may say that she has sailed 7 miles in an easterly direction, although, owing to the necessity of tacking, the straight line *AB* does not represent her actual course, which is represented by *a*, *b*, *c*, *d*, *e*, and *f*. Now, although the vessel has undergone a series of displacements, *a*, *b*, *c*, *d*, *e*, *f*, her nett displacement is the vector g from *A* to *B*. A single displacement equal to *g* would have carried her from her starting point to the point where her course ended. The vector *g* is said to be the sum of the vectors *a*, *b*, *c*, *d*, *e*, and *f*. Note in particular that the sum of a number of displacement vectors which form a closed figure is zero, for the point which is supposed to undergo the displacement comes back to its starting position and the nett or ultimate geometrical displacement is zero. We must take it as self-evident that displacement vectors are added by the method explained above. Evidently, then, if it is required to add together the vectors, *w*, *x*, *y* and *z*, in Figure 18, the procedure is as follows:—Make them the sides of a polygon, taking care that their arrow heads are circuital, then the last side of the polygon with a non-circuital arrow head represents their sum. It is easily seen that the order in which vectors are added together does not effect the result. Using a system of notation, introduced by Bow, mechanically enables the above rules to be observed. The vectors may represent displacements, velocities, accelerations, momentum, impulse, forces due to gravity, electricity and magnetism, etc. As soon as we comprehend the statement of the addition rule we see that it requires no proof. This polygon rule is the fundamental rule when dealing with vector quantities. With a few more simple rules, or constructions, apparently most intricate and difficult problems can be easily solved by purely mechanical graphical systems or methods. The graphic vector method has generally also the important advantage over the analytical method that it is self-checking. Fig. 19 shows the graphic static method of obtaining the stresses in the various numbers of a camel back and a petit truss, respectively, due to the dead load on the structure. The results are obtained by drawing, to scale, vector (force) polygons similar to the ones just described in Fig. 18. Fig. 20 shows more examples of graphic statics and vector polygon analysis. *AB* in the upper diagram represents a

beam carrying a varying load. Curve on A_1B_1 gives the shearing force, curve on A_2B_2 or $A_{\frac{1}{2}}B_{\frac{1}{2}}$ gives the bending moment curve. Curve on A_3B_3 gives the slope curve, and on A_4B_4 the deflection curve of the beam. Lower diagram shows the construction for obtaining the moment of inertia of the shaded beam section on the left. Fig. 21 shows the graphic static method of obtaining the line of pressure in a masonry arch bridge, and thus ascertaining its stability. Live load, dead load and earth pressure have been taken into account. The method is purely a graphical one and depends mainly upon the vector polygon. The science of dynamics is largely that of the equivalence of vectors. Fig. 22 shows four illustrations of the solution of problems dealing respectively with the Pelton Wheel, Centrifugal Pump, Kinematic Chains, and the Balancing of Rotating Masses. Evidently graphic solutions are easily obtained. Fig. 23 shows two indicator diagrams of gas engines. This is a graphical representation of the pressure inside the engine cylinder, the indicator pencil being the draftsman. Fig. 24 shows the construction of the electromotive and current diagram in an A.C. transmission system, which is based partly on the vector polygon. The results obtained from this diagram have been plotted to form the squared paper curves given in Fig. 3. Fig. 25.—The upper figure represents a tripod which sustains an inclined load KV. The construction shows the method of obtaining the thrusts in each leg of the tripod by means of the vector polygon. The lower figure represents a frame with its corners hinged to the ground and carrying a load of one ton. The construction shows the method of obtaining the forces in the six upper bars by means of the vector polygon.

Before attempting to show that graphic methods are indispensable, it is necessary for us to realize that the functions of the craftsman and the engineer are entirely different, and to recognize that persons engaged in the engineering industry may be divided into two principal classes, manual workers and thinkers. In times gone by, manual training alone enabled the apprentice to become a master craftsman, for engineering was an art. At the present time, however, a vastly different training is required to turn a schoolboy into a professional engineer, for engineering now is an art and science. The artizan, or engineer workman, and the highly trained engineer constitute two different problems. It is also necessary to differentiate between the two types of highly trained engineers, the technological and (for want of a better name) the academical. In training the former consideration is given to the commercial and business side of engineering, as well as the applied scientific, while in the latter the scientific side alone is really dealt with, and is consequently more theoretical than a technological course of

study. The technologist is trained to foster through science the development of industrial arts, and the academical to foster merely the development of industrial science. According to the dictionary, as far as we are concerned, "technical" means pertaining to the art of engineering, "technological" to the science of industrial engineering, and "academical" to engineering applied science.

It is believed that for our welfare in general and the interests of engineers* in particular the following institutions, each with its own definite purpose, are necessary:—

(1) The Technical School (Junior and Senior) for the artizan, for providing suitable instruction for foremen or supervisors, and manual workers.

(2) (*a*) The School of Technology, for the technologically highly trained engineer, for providing suitable courses of study for producing scientific advisors and designers, with due regard to the commercial and investigation aspect, and managers and business organizers.

(*b*) The University School of Engineering for both the technologically and the applied scientific highly trained engineer; for providing suitable courses of study for (i) the technologists as in (*a*), and (ii) the engineering scientist, for producing scientific advisors and designers concerned principally with scientific research and having little regard to the commercial aspect.

Typical examples only will be given in dealing with the application of the graphical methods, and it will be convenient to assume that the two principal classes are dealt with as follows:—

(1) *Apprentice.*—Enters a Technical School, takes a technical trade course, and in the works aims at becoming, say, a skilled mechanic, or else, wishing to advance, continues on with his studies as below.

(2) *Cadet.*—Enters a School of Technology or University School of Engineering, and aims at becoming a highly trained engineer, and after graduating enters a drawing office, prepares designs and estimates, and later, in a minor supervising position, goes on to the actual construction of machines or works, and ultimately attains an important management position.

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* See paper, by the author, "On Education and its connection with the real problem before Engineering Societies," before this Institution, August, 1916.

1. *The Manual Worker or Artizan.*—The object, in the past, of the apprentice has been to become an all-round craftsman. Competent all-round craftsmen have never been too plentiful, and the scarcity is rapidly increasing, for nowadays the tendency everywhere is toward the replacement of manual skill, all round knowledge, and varied jobs respectively, by automatic machinery, specialisation, and repetition work. This substitution ends in the craftsman becoming merely a human mechanical machine requiring no initiative. Thus modern specialisation methods have created an unadaptable industrial population which fosters the production of inferior workmen. The monotonous nature of the work breeds discontent, produces dissatisfaction, and ends, as we all know, ultimately in social trouble. To successfully combat these evils it is believed that the craftsmen, or engineer workmen, must have a sounder vocational (and social) education than hitherto. The war has shown us that the competent craftsman is the backbone of industry, and that his status must be raised, and real skill, natural aptitude and invention must be encouraged. Now, in order to perform his work intelligently, to profit by and make good progress in the instruction given in the classes in technical subjects, an artizan must have a fair knowledge of some of the so-called higher branches of mathematics. Thus, an elementary knowledge of the calculus is indispensable. Yet, in the past, few apprentices or engineer workmen continued on, after their preliminary school training, with the study of mathematics, and very few indeed reached the really useful calculus stage. Undoubtedly with the craftsman the great stumbling block to advancement in technical knowledge has been in connection with the study of mathematics, and since the removal of this obstruction is absolutely necessary, the author believes he is justified in going into the matter at length. The failure of the old academic method to interest students of ordinary abilities and to bring within their reach and enable them to make practical use of some portions of what are generally, though with little reason, called "higher" mathematics, led some years ago in England to the introduction by technologists and applied scientists of practical mathematics. Before the advent of this new method attempts had been made to develop mathematics for craftsmen, on common-sense lines, and this led to the successful introduction of classes like technical and workshop arithmetic, calculations for electrical students, machine calculations, mensuration for builders, engineering mathematics, etc. However, undoubtedly the best attempt to encourage and maintain the necessary interest, and for training to be of practical benefit, is with a set course called practical mathematics. The characteristic of the practical mathematical method is, perhaps, the domination of graphical analysis and the subordination of

abstract reasoning. It follows the Applied Scientist laboratory idea of learning by doing, and not by thinking alone. Instead of abstract logical deduction first and particular application afterwards, as in the academic, the symbolical deductive treatment is anticipated by well-chosen particular applications at every step by graphic and arithmetical verification, to enable the student to clearly realize his own experience and see that he is not dealing with an arbitrary system of symbols alone. This method prepares the student for a more rigorous analytical study of the subject. The Calculus is introduced early, for it is recognised that although many mathematical rules may be obtained by the so-called "elementary" methods, that these are frequently only roundabout and troublesome tricks, and are, after all, merely expedients to evade the simple notation of the Calculus, which are quite as difficult for the student to grasp as the underlying principles of the Calculus. Thus, take the problem of determining the moment of inertia of a rod; when once the student becomes familiar with the easy language of the Calculus, all the scaffolding, which has to be so carefully and tediously built up to obtain a result if algebra alone is employed, may at once be discarded. Vectors also are introduced early in the course, for the important subject of mathematical and graphical vector analysis is the common foundation for subjects involving vectors, such at Statics, Dynamics, Hydrostatics, Hydrodynamics, Electricity, etc. Almost immediately after the introduction, some years ago, of practical mathematics classes, the enrolment in the mathematics classes in the Manchester district, England, increased ten-fold. Instead of having, say, merely 50 mathematics students, the average for many years at a branch Technical School, or School of Technology, the numbers rapidly increased to 500. There have been great increases every year in the newer classes, while about the same number, say 50, still continue to take the old academic course.

Through lack of time, one other example only of the application of graphical study will be given. It will be assumed that the student enters an Applied Mechanics class. A few years ago, the course of study consisting of lectures only, was only partially successful, but nowadays a laboratory training, in conjunction with the lecture work, has made the course completely successful, owing largely to indispensable graphics. Thus a portion of the subject, such as "stress and strain," is introduced in a lecture. Since the definitions of "stress and strain" are mere convention, they have to be gotten off by heart by the student, but the connection, within the elastic limit, between "stress and strain"—the celebrated Hookes' law—namely, stress÷strain=constant, for any given material, can easily be verified by the student himself. Immediately after the lecture the student, in the Applied Mechanics laboratory, proceeds to

carry out various strain experiments on, say, glass, indiarubber, timber, string, iron, and copper wires, and steel bars. Experiments on the various kinds of strains are made, namely:—Tension, compression, shear, bending, and torsion. Thus, for example, a stretched wire is loaded with known weights, and its alterations in length obtained. After the student has taken the necessary observations, the results, showing connection between the weight on the wire and the alteration in length it produces, are plotted on squared paper. An average curve is drawn evenly between the points. This corrects errors of observation, and, moreover, is the most accurate method of correction. Before graphical methods were introduced, complicated analytical methods, such as the least square, had to be used, and they were tedious and inaccurate compared with the simple curve method. In this case the curve, up to a certain point, will be a straight line, so that the law connecting the two variables, up to a certain limit, is such that stress÷strain=constant. In a similar manner by plotting results it is found that other strains—compression, shear, etc.—obey the same law. Thus from his own observations, after plotting graphs on squared paper, the student realizes the truth of Hookes' law. When another portion of the subject, such as "lifting appliances," is introduced in the lecture, corresponding laboratory experiments are made, for boys and men alike learn most effectively by working for themselves, with the "do it yourself" method. The object is to become familiar with the "general law of machines," and in particular to determine the law connecting—

(1) The mean effort and the load.
(2) The friction of the machine and the load.
(3) The mechanical advantage and the load.
(4) The efficiency and the load.

The force required to just lift the weight is obtained, and the results entered exactly as read on a sheet. After taking all necessary observations, the results of calculations are entered also on the sheet, and suitable combinations of the results are now plotted on squared paper and the laws so determined. It will be seen that the law connecting—

(1) Mean effort and load is a straight line.
(2) Friction and load is a straight line.
(3) Mechanical advantage and load is a portion of a rect. hyperbola.
(4) Efficiency and load is a portion of a rect. hyperbola.

The equation to the curves, as plotted, may be obtained and thus the laws and limitations of the machine are determined.

Other experiments (over 80 when complete), all involving graphic analysis, are fully described in a book of Laboratory Instruction and Record Sheets, prepared by Prof. Whitfeld and the author.

2. *Highly-trained Engineer.*

(*a*) *At College.*—The object of the cadet is for proficiency, for high training, for a diploma or degree, and then actual engineering practice. As stated before, it is necessary for our welfare to have the two courses for the highly trained engineer, as set down in the general scheme given some time ago—a technological curriculum for the majority and an academic curriculum for those who are specially gifted or inclined towards the academic. This view is not altogether unorthodox, for the trend of opinion in England is in this direction. The difference between academical and technological methods of study may be considered to be essentially the same as the difference between academical and practical mathematical methods. Thus the characteristic of the technological method of study is perhaps the domination of laboratory and graphic analysis and the subordination of abstract reasoning. As in practical mathematics, the purely symbolical mechanical abstract analysis is anticipated wherever possible by graphical analysis or arithmetical verification. With the great majority of students, "principles" cannot be truly understood or fully comprehended until solutions to particular applications have been carefully worked out, and as the particular applications form an integral part of the technological method, they cannot be overlooked.

The subjects taken at a University or School of Technology may be divided into two groups, thus: those which involve a knowledge of mathematics (*i.e.*, theory and design of structures) and those which do not require mathematical analysis (*i.e.*, descriptive subjects, such as geology). Only graphical illustrations from the first group will be considered Obviously. a sound working knowledge of elementary, together with some of the so-called higher mathematics is essential nowadays for the highly trained or professional engineer. But the engineer needs no artificial mental gymnastics, or examination puzzles, or by evasions of the Calculus, during his early stages, infinite worry with elementary mathematics. A common-sense knowledge of the few fundamental principles is what is required, for the engineer, unfortunately, has usually no time for a complete mathematical training, the engineering curriculum becoming more exacting every year. It is no longer undignified to introduce particular applications before general theory is dealt with. The modern engineering mathematician merely regards "mathematics" as a useful and necessary tool or appliance.

The Schools of Technology in England have, with great success, adopted, partly or wholly, the newer and verile method of teaching mathematics.

In illustrating their use in purely engineering subjects it will be convenient, as stated before, to use the graphical classification used some time ago when considering the different methods of graphing data. The illustrative or bar method is of great use in lectures, enabling students to quickly grasp and assimilate matter that would otherwise be troublesome. Thus simple diagrams may be used to show—

- (*a*) The relative strains in various materials when subjected to a stress of, say, 5,000 lbs. per sq. inch;
- (*b*) The effect of the character of the stone upon the cost of concrete. It is seen that if the percentage voids is small there will be a larger mass of solid stone in a given volume of loose stone;
- (*c*) A method of illustrating the relation between the pressures and velocities during the passage of the steam through an impulse turbine of the De Laval type;
- (*d*) The scheme of the multicellular turbine;
- (*e*) The heat losses in an ordinary coal suction gas plant;

and so on.

In the majority of engineering problems the number of variable quantities which effect the result is seldom less than half-a-dozen—often a dozen or two. Even if a result could be obtained, a formula containing so many variables would be too cumbersome in practice. In consequence, in the past it has been found expedient to introduce simplifying assumptions; in other words, to eliminate all but average essential variables, so that a not too involved solution may be obtained. Different authorities having different ideas as to what are the essential variables obtain, with perfectly correct mechanical mathematical analysis, different solutions to the same problem. The general distrust in theory is partly due to the fact, an obvious one, that the resulting formulæ very often give erroneous results. Clearly, unless the fundamental assumptions—the so-called premises or essential variables employed in deducing a law or formula—are remembered when using the formula, serious mistakes are likely to be made. It must be carefully noted that mathematical reasoning alone, in engineering problems, does not justify the indiscriminate use of resulting formulæ, for the vast majority of our formulæ, for practical use, give only approximately true results between certain fixed limits. It is surprising how many of the old theories have com-

paratively recently been proved to be wrong. The graphical analysis methods are to a great extent responsible for this rationalisation, for they determine the laws, and show tendencies and give pictures of the operations of the variables which is altogether much clearer than if we merely consider the actual law which described their actions. They enable the telescope, as well as the microscope, to be used. Thus, Fig. 26 shows the normal wind pressure on roofs according to different theories. Only three well-known laws, out of many, have been plotted. Now all these formulæ give, as far as one knows, equally correct practical results, and so it may be regarded as a waste of good time to bother much with the complicated formulæ. To the technological student, who wishes to apply his knowledge in practice, the simple straight line formula is the one to use and become thoroughly familiar with, the other two only being briefly considered. Fig. 27 shows the various graphs of the formulæ used in obtaining stresses in thick pipes, due to internal fluid pressure. Otherwise, using the apparently more exact Clavarinos analysis, much time would have to be spent in deriving it, for the analysis is fairly involved (a solution was produced). Although this analysis may be regarded as valuable from the mathematical standpoint, it is doubtful whether it would be of any real use to the ordinary engineering student. To the technologically trained man, who wishes to rationally apply his knowledge, the simple Barlow straight line formula is the one to use. This view is further emphasized when applied to ordinary commercial products, for the theoretical error, on the side of safety, resulting from its use will generally not exceed the actual combined error, on the side of danger, when using Clavarinos formula, due to ordinary range of variation in thickness of the wall, in strength of material, etc. Thus in practice the complicated Clavarinos formula does not give more accurate results than the simple easily remembered Barlow. Fig. 28 shows, firstly, the effect of super-elevation on the overturning speed of a steam locomotive. It has been usual to state definitely that the reason for raising the outer rail on curves was due to the fact that it produced great stability against overturning. However, a few years ago a technologist plotted curves to show the effect of super-elevating, and found it to be small and not worth considering in practice, as seen in the diagram. Now the formula for this overturning speed has been used many times, but all the time the mathematical super-elevation-overturning effect was not understood—it required plotted graphs to enlighten us. The diagram also shows approximately the derailing, or jumping the outer rail, speed in going round curves. It is noticed that it is invariably less than the overturning speed, so that the latter is actually not worth bothering

about. When considering derailing, super-elevating the outer rail may be dangerous, for if the locomotive rounds the curve at less speed than the normal speed obtained from the super-elevation, there will be less downward pressure on the outer front wheels, so that the tendency for the outer wheels to mount the rail will be increased. We now know that the super-elevation is desirable for the comfort of the passengers only.

In Fig. 29 is a typical example of law-determinations. The lower diagram shows autographic records of tensile tests of various commercial steels of normal quality after annealing. It is seen that there appears to be some connection between the strength and the percentage carbon in the steel. Just recently the ultimate strengths, as seen in the upper diagram, were plotted against their respective carbon content and evidently a straight line law exists. The equation to this straight line is: Ultimate strength in tons per sq. inch$=51\times$per cent. carbon$+16$. Now, ordinary steels containing up to 0.9 per cent. carbon, when examined under the microscope, after being etched, are found to consist of pearlite blocks and free iron blocks. Pearlite is a conglomerate constructed of alternating sheets of iron and cementite, and is easily recognised. Cementite is a chemical compound of iron and carbon having the definite formula Fe_3C. Annealed steel containing about 0.9 per cent. carbon is built up of blocks of pearlite only. Evidently then the percentage pearlite present $= 111 \times$ per cent. carbon. This scale has been plotted in upper diagram. Obviously, when per cent. $C=O$ (*i.e.*, where straight line cuts vertical axis) we have the ultimate strength of pure iron or ferrite=16 tons per sq. inch. (It is surprising how many attempts have been made in the past to obtain the strength of ferrite—in most cases attempts were made to produce absolutely pure iron.) Also when per cent. C=0.9, when dealing only with pearlite, the ult. strength is 62 tons per sq. inch. Evidently from the diagram the strength of annealed steel depends jointly upon the strength of iron (ferrite) and the strength of pearlite. Fig. 30 shows the result of a systematic study of the properties of all the alloys of chromium-copper-nickel, with reference to those having possible commercial values. In the nickel-rich corner of the diagram the alloys have very large polyhedral crystals and a coarse texture, and have, usually, developed blow holes in casting. The alloys containing large percentages of chromium have such high melting points and are so hard to prepare that unless they find special and important applications, there is little chance of their being used commercially. Alloys containing large percentages of copper with chromium show such a marked segregation that they do not machine well and their chemical properties are poor. The region of commercial possibilities for future investigations, which promises best from

a mechanical and physical standpoint, is also highly resistant to corrosion.

Fig. 31 shows an alignment chart for obtaining the flow of water in C.I. pipes, based upon Flamants' formula for C.I. pipes after a few years' service. It is seen that the alignment chart method offers little chance of error. Fig. 32 shows the vector analysis method of designing reinforced concrete highway bridges. The elevation and dimensions of the arch are assumed and the horizontal thrust in arch determined by polar graphical construction. The probable line of thrust in arch is obtained and the stability of the arch determined. Fig. 33 shows the vector analysis stability diagrams for dry dock design. Here water pressure, earth pressure, thrust and arching actions are considered. Fig. 33 (*a*) shows the influence line method of obtaining the maximum and minimum stresses in various members of a structure, in this case a 3-pinned spandril arch due to a live load. The comparatively new purely geometrical influence line method should be used almost invariably when dealing with rolling loads. Thus, for stress in *FB* the section *XX* must be considered and moments taken about joint *E*. The influence line for stress in *FB* is such that when the load is at *W* the stress is $W \times m \div u$. The maximum and minimum effect of a load rolling over can be obtained by inspection. Uniform loads can easily be dealt with.

(*b*) *In the Drawing Office.*

It is soon realized in the drawing office that the commercial aspect—cost—is of first importance. The scalar and vector diagram graphical methods used at college will be the basis of scientific designs, a few illustrations of which have already been given. The opportunities, however, for using squared paper to advantage in other directions, such as commercial standardization and costing, are innumerable. Thus, in designing standard articles, the principal dimensions and sizes should be plotted to a base of or against the size of the object. For example, curves representing the principal proportions of the various portions of, say, plummer blocks, wall brackets, hangers, couplings, etc., should be plotted to a base of the size of shaft when any discrepancies or irregularities can be detected and remedied at once. It is really surprising how many straight line laws exist. Similarly, the fundamental sizes for steam engine design may be plotted to a base of diameter of cylinder or horse-power, when it will be seen at a glance where the various parts are deficient or in excess compared with the general tendency of the series. Fig. 34 shows some of the results obtained from a series of single-cylinder steam engines. The diameter of piston rod, crank shaft and cross-head pin have been plotted respectively to a base of a diameter of cylinder.

It is seen that the piston rod and cross-head pin for the 9 in. and 10 in. cylinders are weaker than the average. Curves should also be plotted for the sizes of the more important details, such as stuffing boxes (plotted to base of size of spindle), connecting rod ends (plotted to a base of diameter of pin), etc. With a standard series of curves such as this for the guidance of the draughtsmen the work is kept more uniform. In structural design before the stresses in the various portions can be obtained their probable weights must be known. Fig. 35 shows typical examples of the weight of railway bridges. Evidently after designing single track deck plate girder bridges for various spans and live loads the actual weights have been plotted to a base of the span, and the even curves obtained. As before, discrepancies or irregularities can easily be detected and corrected. By interpolation the weights of similar type bridges of other spans can be obtained. The curves may also, of course, be used for type comparison purposes.

Curves showing actual costs of all the standard sizes of the specialities made by a firm are of the greatest possible assistance to the estimating department. For example, curves showing the nett cost of various plummer blocks, wall brackets, hangers, couplings, etc., should be plotted to a base of either the size of shafts (d) or diameter of shaft squared $(d)^2$. Similarly with steam engines, Fig. 36 shows the cost of compound tandem steam engines, of high class design, including rope, fly-wheel, and jet condenser, plotted to a base I.H.P. developed when working with steam at 100 lbs. pressure expanding ten times, at a piston speed of 600-700 feet per minute. In this case the law of the cost curve is approximately—

$$\text{Cost in £'s} = 2.75\ (\text{I.H.P.}) + 440.$$

The cost per ton of nett weight is also plotted to the same base, showing the uniformity of the series. An additional curve for comparison with other types of engines could be plotted showing to a base of I.H.P. the cost of engine per I.H.P. Fig. 37 shows the actual cost of planing machines plotted to a base of length $\times$ width planed. The straight line law is—

$$\text{Cost in £'s} = 3.35\ (\text{length ft.} \times \text{breadth ft.}) + 60.$$

Again, where repetition work is done diagrams showing the cost of machining precisely similar articles and machining different sizes are very valuable. For example, Fig. 38 shows the cost of turning and boring various diameters of fly-wheels plotted to a base of diameter of wheel. Again, where bonus or other systems are in use, squared paper affords a ready means of checking the prices for the various sizes of standard articles made. Thus, Fig. 39 shows the bonus price paid for moulding small cylinders for rotary pumps, plotted to a base of capacity of pump in gallons per minute. In this case the

smaller sizes were moulded in the sand from iron patterns, but the larger sizes were struck up in loam, with strickle boards. It is seen that the prices paid for the various sizes fall almost exactly on two straight lines. In estimates for structures, diagrams similar to Fig. 35, giving, in this case, the probable weights of steel work, enable rough cost or preliminary estimates to be determined. Practically all drawing office work is done under the compulsion of a time limit, often a very short one. An engineering system has to be in operation at a certain date, or machinery has to be designed and constructed in time to catch a certain steamer, and it is necessary that drawings be prepared, and orders and work placed sufficiently in advance of these dates, so that promises may be fulfilled. In order that estimates may be produced in schedule time, it will be necessary when the number of estimates is large to use a progress chart.

Fig. 40* is a typical example of a drawing office progress chart. The key at the top of the chart explains the meaning of the symbols, and the time division by weeks (approximately) is apparent. The order of the method of working is as follows:

(i) Making out a list of the main items of machinery or work and placing them in convenient order under the "Subject" column.

(ii) Then, using red ink, the forwarding or shipping date of each item is indicated by the letter "S" in the case of material, or "d" in the case of drawings. Knowing from past records the probable time required to obtain delivery, the letter "O," indicating date at which order must be placed, is next located in red a corresponding time before the "S." If it takes a month, say, to obtain bids, and place an order after the drawings and specifications leave the office, the date at which they should be sent can then be indicated by a red "D" sufficiently in advance of "O." The dates at which it will be necessary to start such drawings can be indicated by a red "X." Red lines should then be drawn connecting "X" and "D" in order that the "vital period" may be more forcibly expressed. An inspection of a chart thus prepared will show the chief draftsman at a glance the magnitude of the work ahead, and enables him to make the necessary provision for carrying it out. In practice, of course, many con-

* Quoted from Davis: "Engineering Office Systems and Methods," Chap. X.

ditions which cannot be foreseen will arise to alter the ideal schedule, but these uncertainties are not sufficiently great to counteract, in any large degree, the value of the schedule.

(iii) As the drawings are sent out and orders placed, these events may be noted by properly placed marks, "D" and "O" in black ink. At the time the black "O" is marked, the letters "A" (contractor drawing approved) and "d" (drawings to the field) should be placed in red. These letters in black show that this part of the work has been disposed of, and they are also valuable for future schedule planning. At convenient intervals, say once a week, the chief draftsman, by running down the list, may inform himself of the progress of the job, and make necessary arrangements to hurry up any part that may be falling behind the schedule. A pencil check mark at the head of the list may be used to indicate when such inspection was made.

(iv) When the material has been shipped or forwarded and drawings sent to the works (indicated by black "S" and "d"), a blue check mark at the end of the line will show that the work on that item is closed.

Progress charts will be dealt with generally under the next heading.

(*c*) *In the Works.*

Here again the plotting of the results of working will bring into prominence many important points which would otherwise be overlooked, and also enable opinions on costs, progress and performance of work to be correctly and quickly formed. It eliminates, as far as possible, mere guessing. It is, perhaps, unnecessary to state that the charts used by one company or concern can hardly ever sucessfully be appropriated "holus bolus" by another. Fig. 41 shows a chart for track re-construction. It was prepared by a street railway company to ensure restoration of street service within the time granted. A little study of the chart will render its utility clear. A system of colours to show the relation of the "work performed" to the "work planned" will also be suggested. A typical example of combination cost and progress charts will now be given for a concrete construction job. Three progress charts are made out —one to cover labor cost only, one to cover expenditure in materials, and a third giving a summary of the other two. Fig. Figure 42 (*a*) shows the chart for expenditure for labour.

About two-thirds the way up from the bottom a heavy horizontal line is drawn to represent the estimated quantities and costs, or 100 per cent. This line also represents the time for completion as shown in the contract. To illustrate the method of construction, suppose it is estimated that 4,000 cubic yards of concrete are required, and the total time for completing the work is 4 months. If at the end of the second month there are only 1,000 cubic yards in place, the cross hatching under column headed "Concrete cubic yards actual" will be advanced from where it was the previous month to a point, 1,000 cubic yards $\div$ 4,000 cubic yards $\times$ 100 per cent. $=$ 25 per cent. from the base line of the chart. In the same column the same style of cross hatching (only dotted) will be advanced to a point 2 months $\div$ 4 months $\times$ 100 per cent. $=$ 50 per cent. from the base line. This shows, of course, that for this particular item that it is only 25 per cent. completed, when to finish according to schedule time 50 per cent. should be completed. The valuable unit costs for each month are written in small figures in the total cost column. Figure 42 (*b*) shows the chart for expenditure on materials of construction, constructed similarly to Figure 42 (*a*). Figure 42 (*c*) is merely a summary of the two just described, together with the plant expense chargeable to that job. The first cost, in the case of new equipment, and the invoiced value, in the case of second-hand, is charged directly on each job as it is placed on the work. Then the invoiced value, if moved to another job, is given as credit, leaving the balance as the depreciation or cost of plant for that job. One striking advantage of charts of this nature is that on the final entry being made they stand as completed job summaries, both as to details and as to totals, and filed away with a construction progress drawing form a very complete record for use in estimating other works. Fig: 43 shows a typical chart for monthly comparison of manufacturing costs. The method of compilation is apparent. It is evident that as long as the area under the sixth line does not project above the seventh line there is a probability of profit.

(*d*) *General Manager or Modern Consulting Engineer.*

Progress charts similar to those already considered under (*b*) Drawing Office, and (*c*) Works, will, of course, be used by the general manager. An organization chart, kept up to date, of the "family tree" type, is essential nowadays, for it has the following advantages:—

(i) It clarifies the general manager's or chief engineer's own ideas, compels him to justify the existence of his principal assistants, and calls his attention to desirable increases or decreases in the size of his staff.

(ii) It enables the department or concern to detect faulty organization methods or to make helpful suggestions.

(iii) It shows the men to whom they are responsible, and so eliminates disputes as to authority.

The two following figures illustrate in a forcible manner the relation of the engineer to capital, labour and production. Fig. 44 (*a*) shows the method of organization, if any, at the beginning of this industrial age. Capital and Labour are here represented without organization. The owner and workman (that is, Capital and Labour) intermingled as one to achieve production. Fig. 44 (*b*) shows the method of organization recently put forward as the best under modern conditions. It is noticed that the "capital" and "labour" are controlled and brought together by the "chief executive."

The remuneration of labour problems are generally somewhat involved. As is well known, day work is the oldest form of wage system and the most widely used, and under it the workers are paid by the hour, day or shift, regardless of the quantity of work produced. Piece-work is the second oldest form, and, next to day work, is the most commonly employed, and under it employees are paid by the piece, regardless of the time taken. There is little difficulty in understanding the above systems, but with the newer premium or bonus wage systems, which recognise both output and time taken, the assistance of charts or graphs are necessary for a clear understanding of the various features of the different systems. It is, however, exceedingly difficult to reduce them to a perfectly fair level in order to make a comparison. Thus in some wage systems, noticeably differential piece-work and the Gantt bonus system, the exceptionally fast and skilled worker is taken in determining the base, standard or specified time, while in other systems the average worker is used. Fig. 45 shows some graphs of the rate and wages of various wage systems. In straight piece-work the price has here been taken to be the same as in the premium systems when the piece is completed in the so-called base or standard time. In the Halsey premium system, the time saved is usually divided equally between the employee and the employer, for ease in figuring, but here has been taken as 40 per cent. to the employee ,in order to compare with the 20 per cent. of the Emerson bonus system. In the Cardullo diminishing premium system, N has been deliberately set at 2 to distinguish it from the Rowan premium system, while in the Gantt system the bonus has been arbitrarily fixed at 50 per cent. From curves evidently, as with the various systems of piece-work, each premium system has certain specially weak features attached to it. Thus, for example, the

Rowan system is not easily understood by the employee; the Cardullo system favours the interests of the employer, even more than the Rowan; the Gantt, like differential piece-work, fails entirely to recognise the effect made by the employee if the standard or specified time is exceeded; the Goldman systems are rather too complicated; and lastly, the Halsey, Emerson and Gantt systems are too liberal to the employee. In the shipping of machinery or other material from a manufacturing establishment to the site of an engineering development certain forms have to be filled in, rules of the road complied with, etc. The details of the work are often complex and bewildering to those unaccustomed to the routine. Diagrams similar to Fig. 46, of procedure in ordinary domestic shipping, in which the numbers indicate the order of procedure, throw considerable light on the subject. Thus, the goods having been properly marked and weighed, are taken to the freight office of the railroad, accompanied by a detailed shipping list if the consignment is large and varied. A receipt for them is given in the shape of a bill of lading signed by the freight agent. Large shippers, however, usually make out the bill of lading themselves, and it is simply signed by the agent. The agent makes out a way-bill, describing and routing the shipment, for the use of the freight conductor; on arrival of the goods at their destination, this way-bill is turned over to the receiving freight agent, who then sends to the consignee a freight bill and notice of arrival. In the meanwhile the manufacturer sends to the purchaser an invoice or bill for the goods, the bill of lading, and a copy of the shipping list (if any). The purchaser then presents the bill of lading to the agent at the receiving station, pays the freight bill (if not prepaid), and takes away the goods. After checking them against the shipping list, and being satisfied of their good order, a cheque in payment may be sent to the manufacturer and the transaction closed. Diagrams for export shipping may be prepared in a similar way.

Much of the work of the general manager or chief engineer is the consideration and recommendation of schemes, and graphs will always help him scientifically. Thus, for example, he may be faced with the choice of a prime mover for a power station. Fig. 47 represents curves based on costs in England, February, 1914, showing the costs of power stations in £'s per k.w. capacity, including electric generators, switchboards, building, foundations, cranes. It is easily seen that, as far as the diagram is concerned, with power stations over 1,000 k.w. capacity, steam turbines alone are to be considered. Other diagrams are, of course, necessary for a proper understanding of the problem. Thus diagrams are required plotted to a base of capacity of plant in k.w., showing cost per k.w. hour, re-

spectively, of oil, waste, water, and stores, and management, salaries and wages, and cost of repairs and maintenance. With diagrams a rational understanding can, comparatively easily, be arrived at.

The advantages of the graphical methods of study, as we have seen, are as follows:—

(1) They present a picture, or bird's eye view, by which the mind's eye can comprehend, at a glance, the nature of the relationship or variation between quantities which are dependent upon one another.

(2) They provide for an easy detection of any unusual variation.

(3) They are a great time-saving device.

(4) They correct for errors of observation and calculation, and are often self checking.

(5) They enable laws and empirical formulæ to be easily determined.

It is noticed that through lack of time the many self-recording curve devices, so necessary nowadays, which necessitate graphic analysis, have not been dealt with. It is interesting to note, however, as we have seen, owing to the fact that many of the graphical analysis methods (particularly the vector) are purely geometrical, that mechanical machines or instruments may be constructed to give the required results. Thus, the well-known Planimeter or Integrator is used for graphical integration (*i.e.*, for obtaining areas). Another instrument, the Integraph, not so well known, differs from the Planimeter, for it draws a curve of areas such that the ordinates represent the area of the given curve up to this ordinate. The Differentiator instrument is used for graphical differentiation (*i.e.*, for obtaining slopes).

The fundamental sciences of engineers—mathematics and physics—are, for our benefit, being re-written in graphical analysis. Graphics are everywhere used in designing bridges, buildings, ships, engines, machinery, and electrical equipment. We realize that charts are necessary in works of construction, management and organization of engineering industry. Graphic methods are indispensable to engineers. Finally, it is evident from the few suggestions put forward in this paper of the study of data by graphical methods that it is a means for lightening the ever-growing technical and industrial burden, not by doing less, but by doing more in much easier fashion.

SOME THOUGHTS ON RECONSTRUCTION AFTER THE WAR.

(By Professor Shann.)

On September 5, 1917, Professor Shann delivered an interesting paper on the above subject.

END OF VOLUME VIII

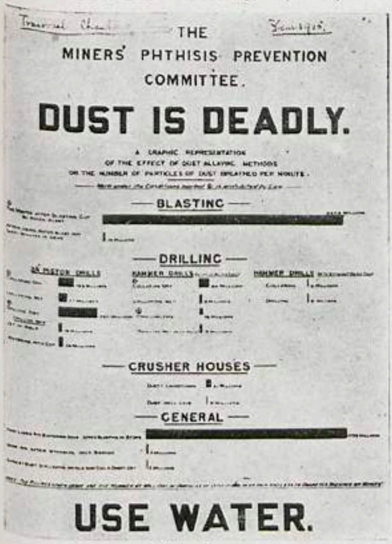


Fig. 1.

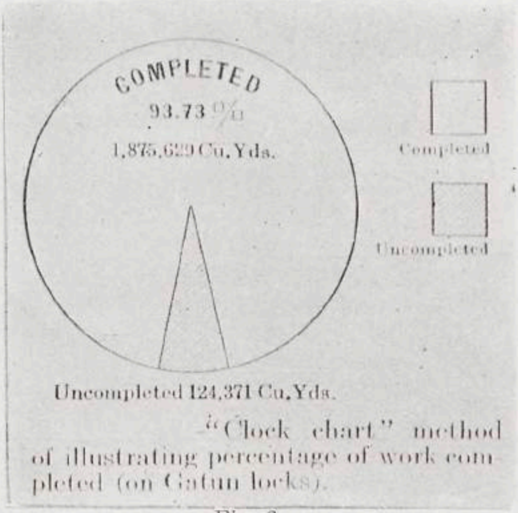


Fig. 2.

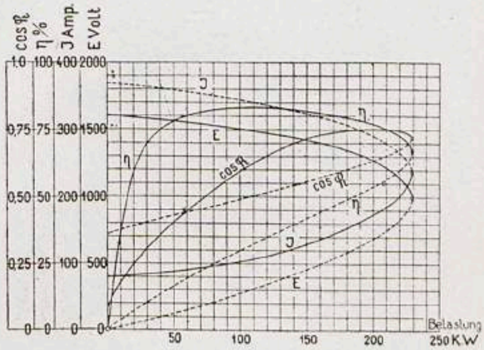


Fig. 3.

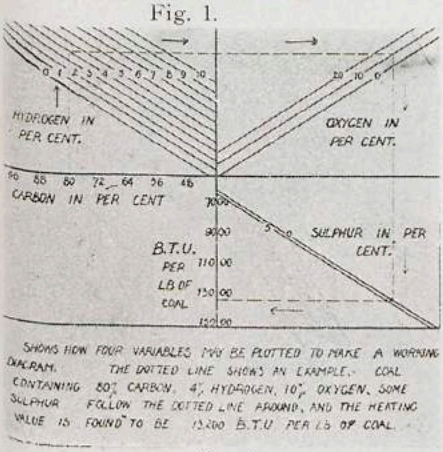


Fig. 4.

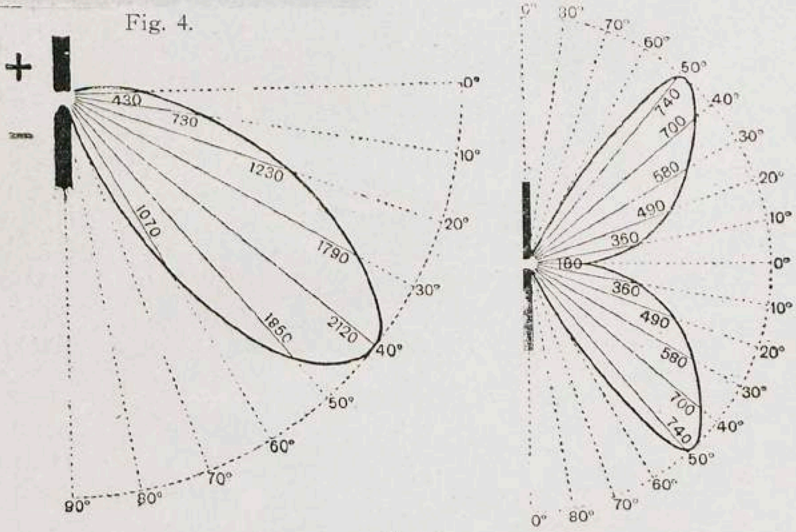


Fig. 6.

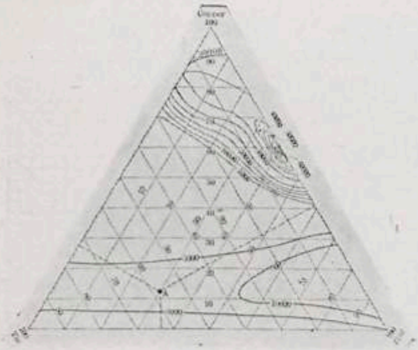


Fig. 5.

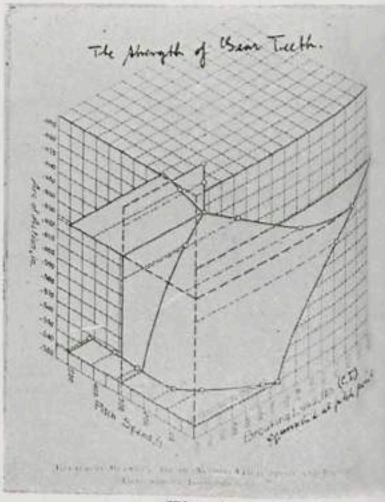
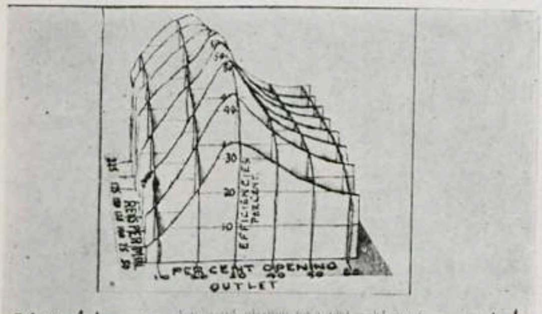


Fig. 7.



Relation between the efficiency of a fan and the area of outlet for various speeds.

Fig. 8.

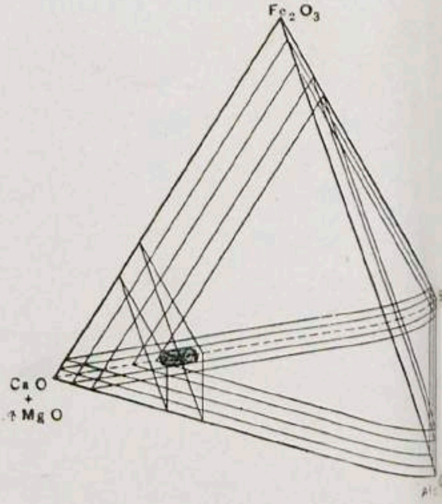
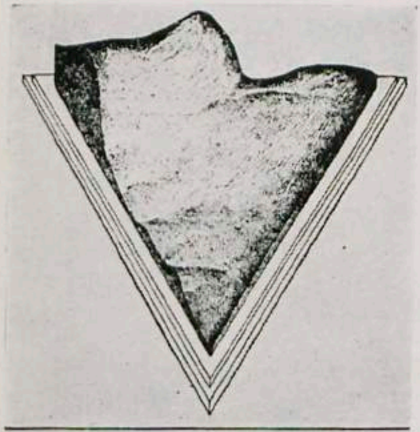


Fig. 9.



–Professor Thurston's solid tri-axial model for copper alloys.

Fig. 10.

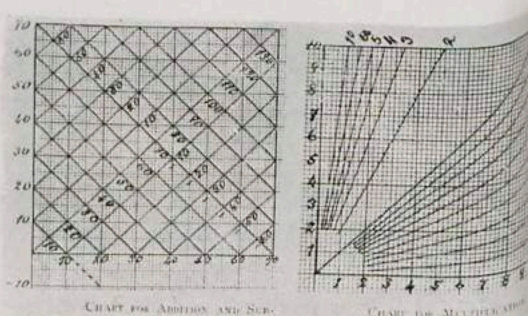


CHART FOR ADDITION AND SUBTRACTION

CHART FOR MULTIPLICATION DIVISION, STRAIGHT LINES

Fig. 11.

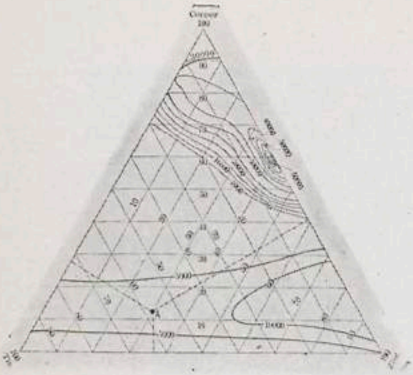


Fig. 5.

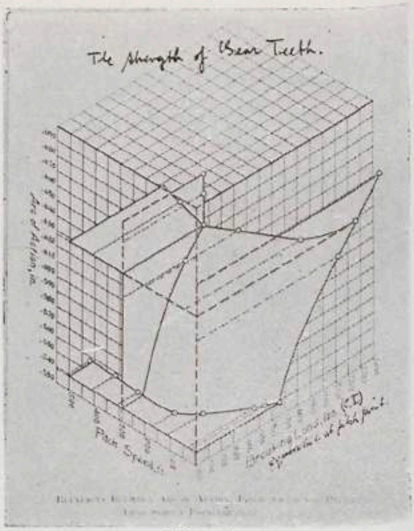


Fig. 7.

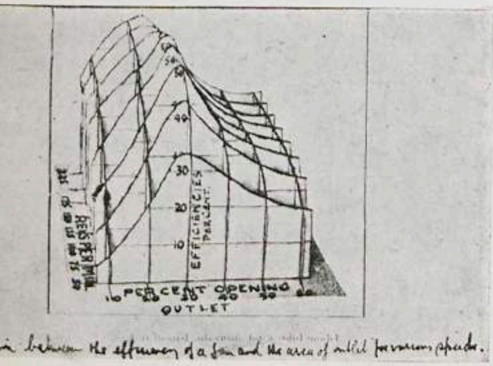


Fig. 8.

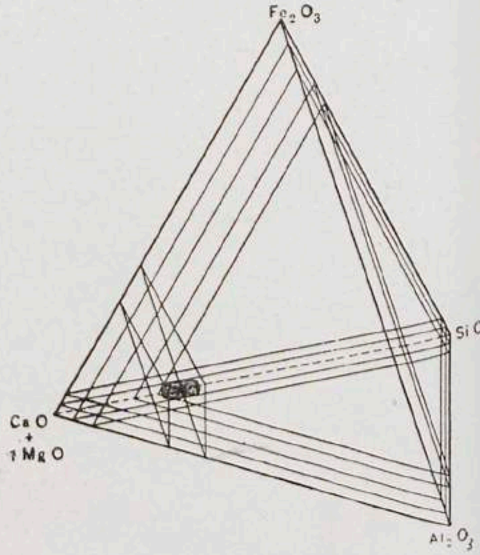
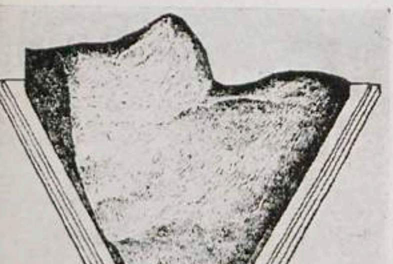


Fig. 9.



–Professor Thurston's solid tri-axial model for copper alloys.

Fig. 10.

Chart for Addition and Subtraction

Chart for Multiplication and Division, Straight Lines

Fig. 11.

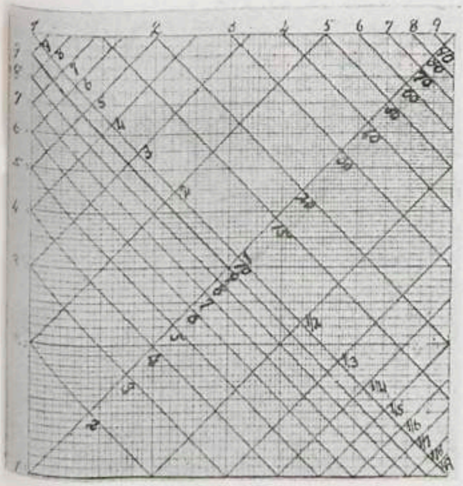


Fig. 12.

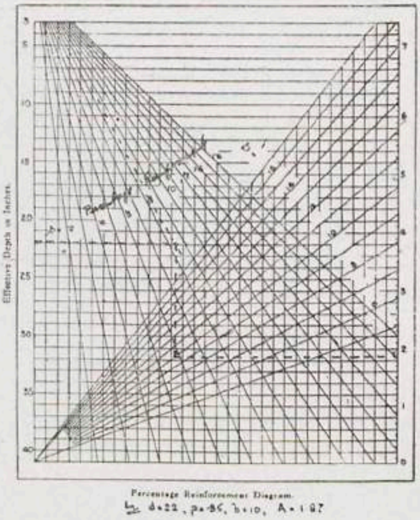


Fig. 13.

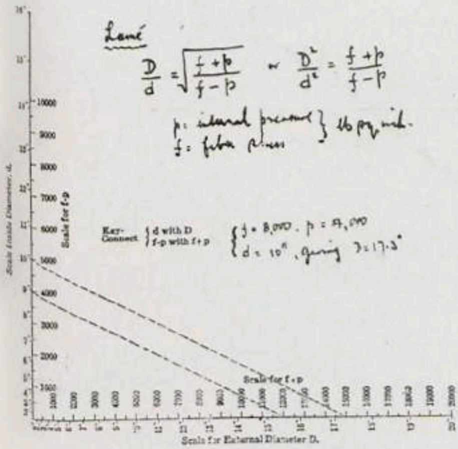


Fig. 14.

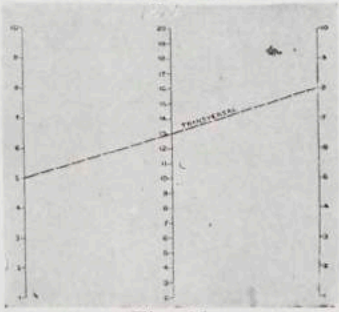


Fig. 15.

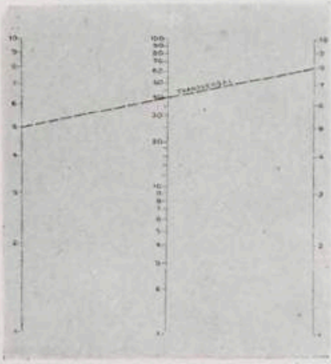


Fig. 16.

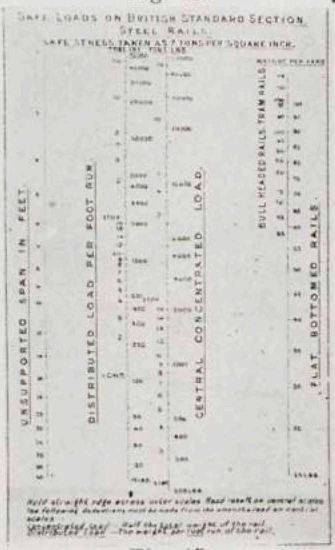


Fig. 17.

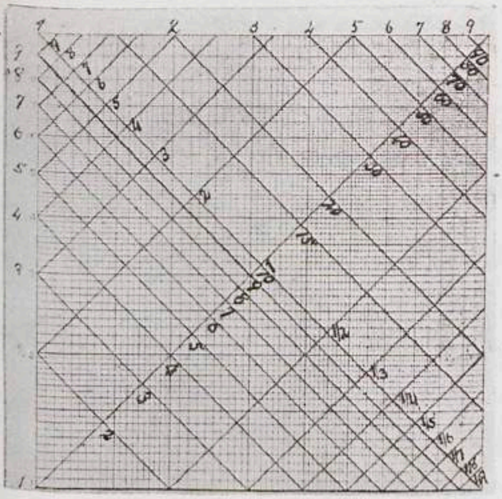
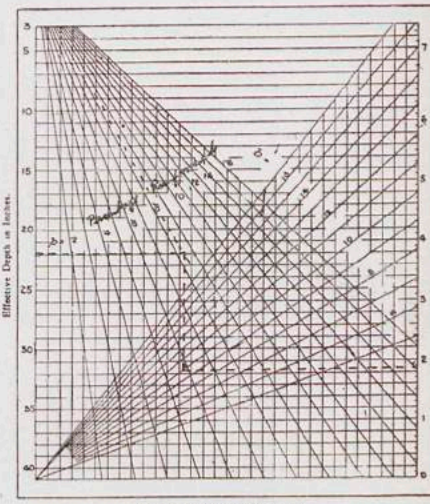


Fig. 12.



Percentage Reinforcement Diagram.

Fig. 13.

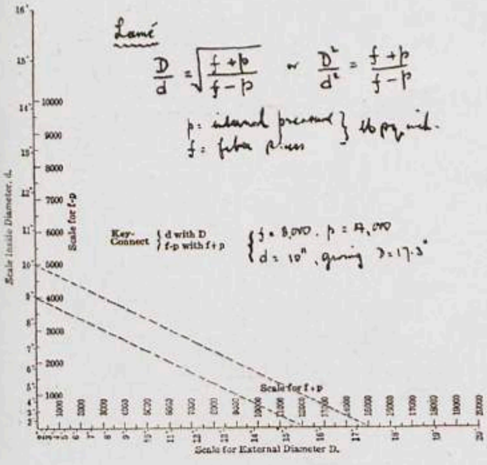


Fig. 14.

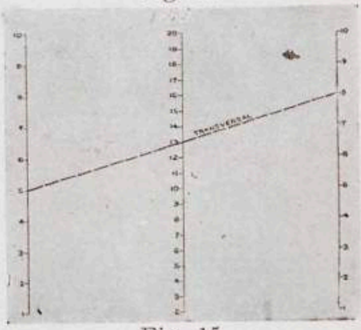


Fig. 15.

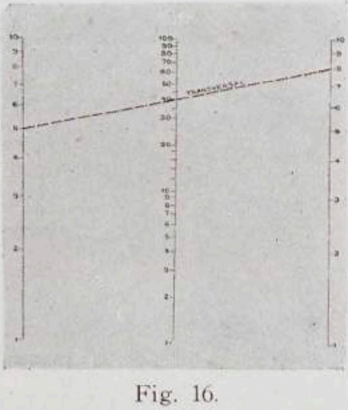


Fig. 16.

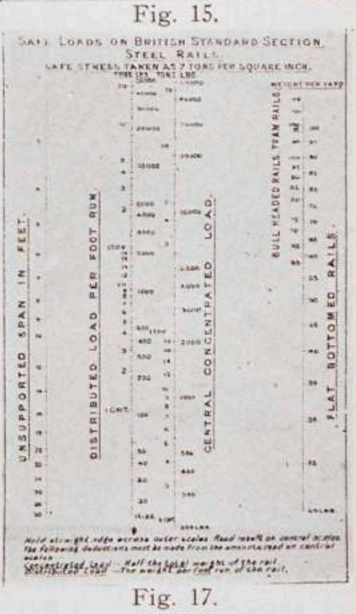
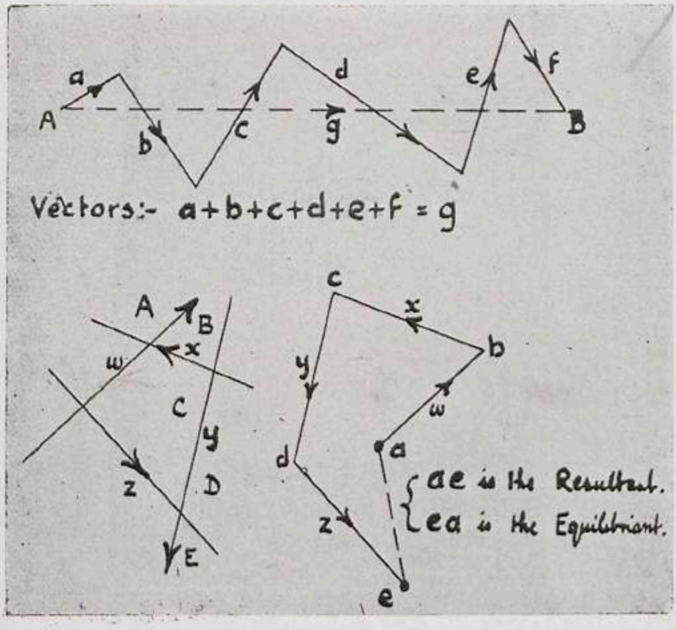
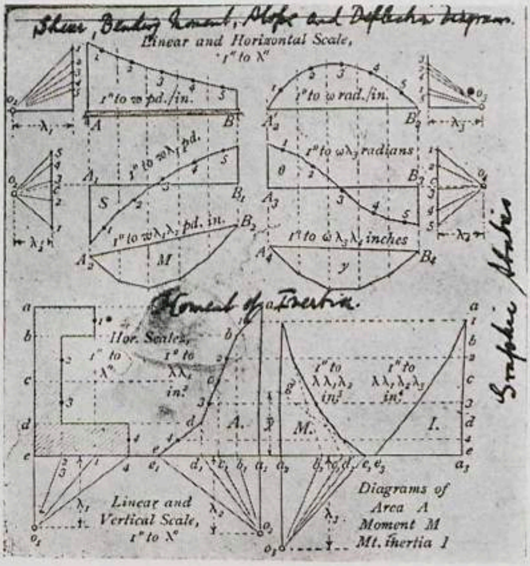


Fig. 17.



Vectors:- a+b+c+d+e+f = g
ae is the Resultant.
ea is the Equilibriant.

Fig. 18.



Shear, Bending Moment, Slope and Deflection Diagram.
Linear and Horizontal Scale,
1" to λ"
1" to w pd./in.
1" to w rad./in.
1" to wλ₁ pd.
1" to wλ₃ radians
1" to wλ₁λ₂ pd. in.
1" to wλ₃λ₄ inches
Moment of Inertia.
Hor. Scales,
Linear and
Vertical Scale,
1" to λ°
Diagrams of
Area A
Moment M
Mt. inertia I
Graphic Statics

Fig. 20.

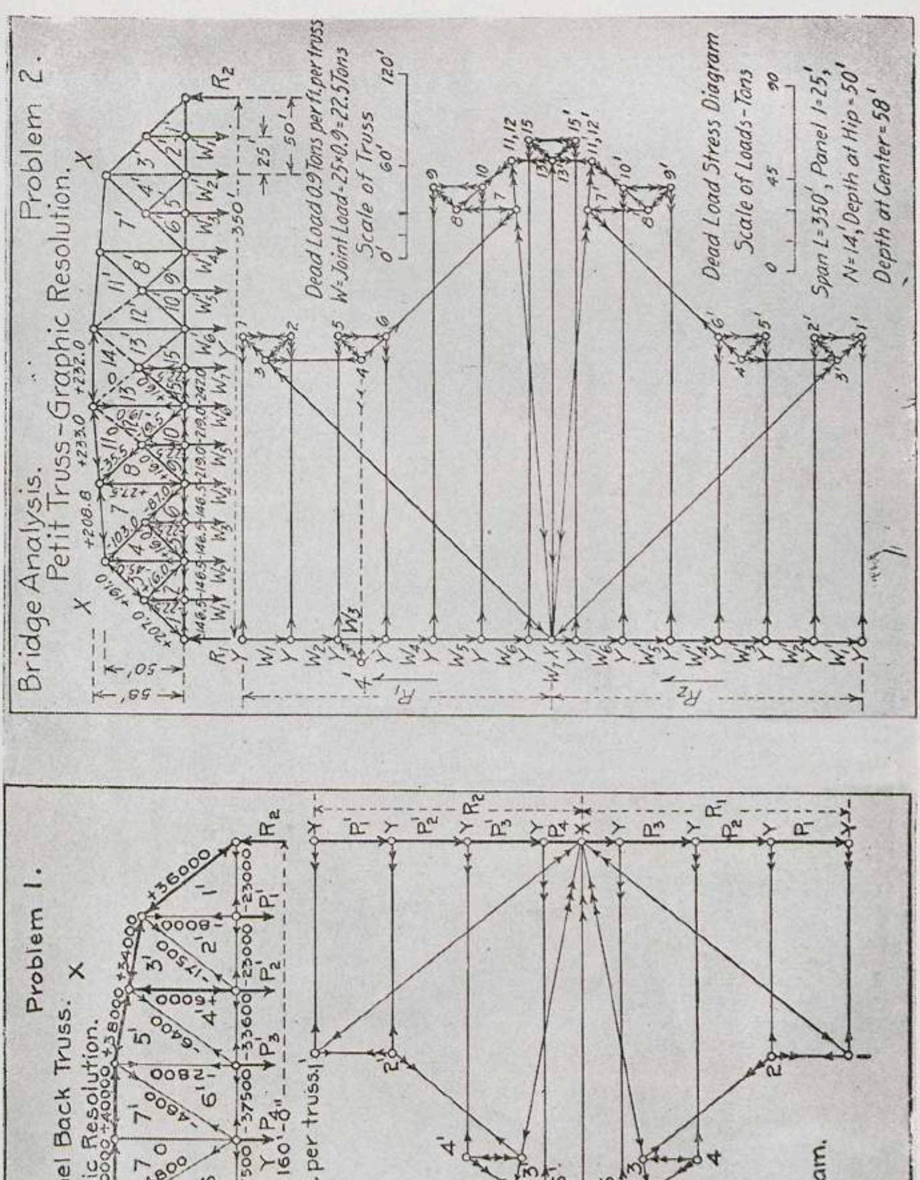

Bridge Analysis.
Camel Back Truss.
Graphic Resolution.
Problem 1.
Dead Load = 400# per lin. ft. per truss.
Joint Load, P, = 8000.#
Span, L, = 160'-0".
Panel, l, = 20'-0".
Depth, d_1, Hip, = 25'-0".
Depth, d_2, Center, = 32'-0".
N = 8.
Truss Scale, 1" = 25'-0".
Load Scale, 1" = 10000.#
Dead Load Stress Diagram.
Bridge Analysis.
Petit Truss-Graphic Resolution.
Problem 2.
Dead Load 0.9 Tons per ft. per truss
W = Joint Load = 25×0.9 = 22.5 Tons
Scale of Truss
Dead Load Stress Diagram
Scale of Loads-Tons
Span L = 350', Panel l = 25',
N = 14', Depth at Hip = 50'
Depth at Center = 58'

Fig. 19.

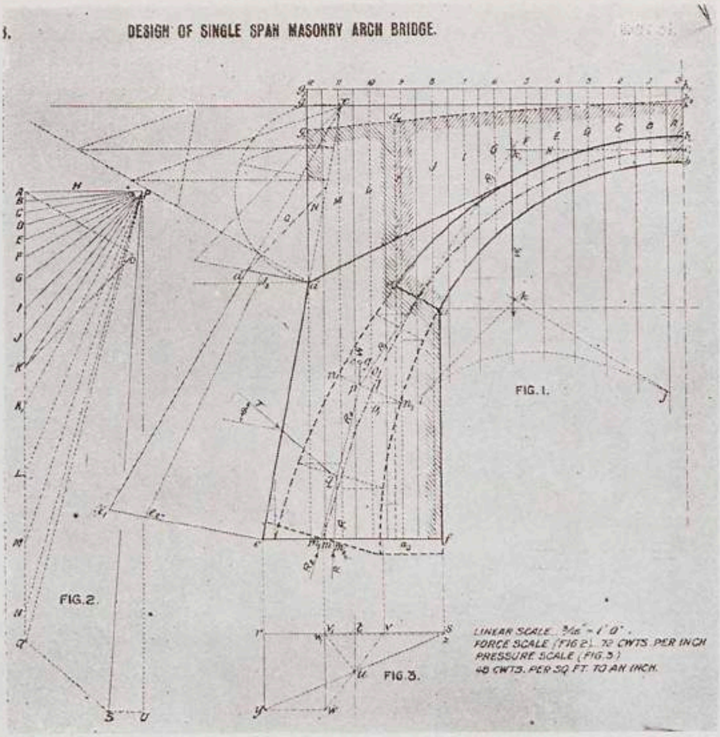

DESIGN OF SINGLE SPAN MASONRY ARCH BRIDGE.
FIG. 1.
FIG. 2.
FIG. 3.
LINEAR SCALE 3/16" = 1' 0".
FORCE SCALE (FIG 2) 72 CWTS. PER INCH
PRESSURE SCALE (FIG. 3)
48 CWTS. PER SQ. FT. TO AN INCH.

Fig. 21.

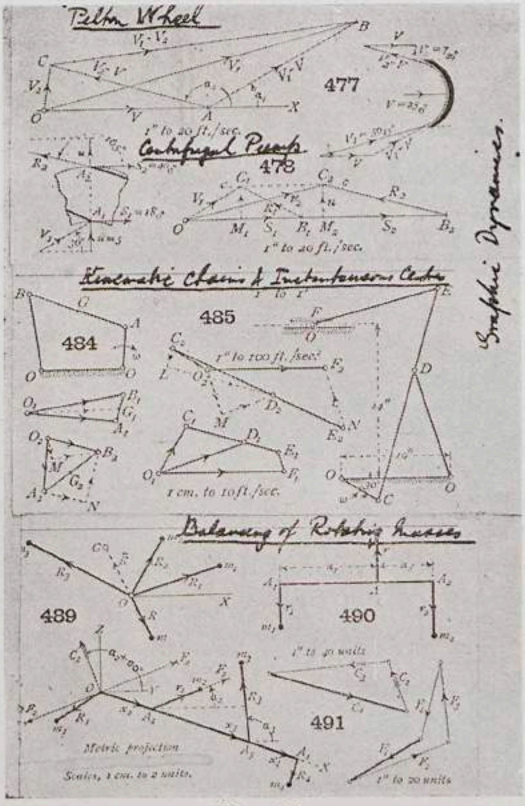

Pelton Wheel
477
1" to 20 ft./sec.
Centrifugal Pump
478
1" to 20 ft./sec.
Kinematic Chains & Instantaneous Centre
484
485
1" to 100 ft./sec.²
1 cm. to 10 ft./sec.
Balancing of Rotating Masses
489
490
1" to 40 units
491
Metric projection
Scales, 1 cm. to 2 units.
1" to 20 units
Graphic Dynamics

Fig. 22.

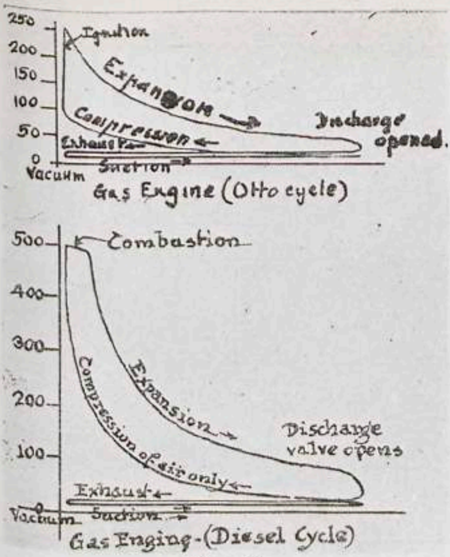


Fig. 23.

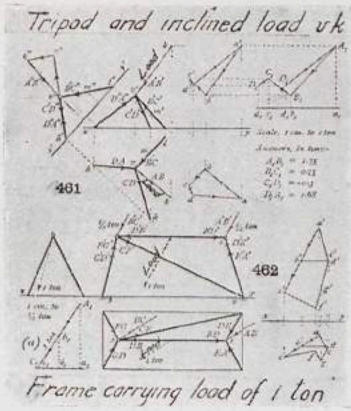


Fig 25

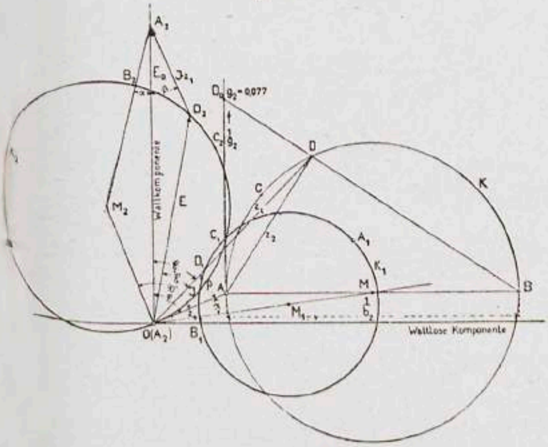


Fig. 24.

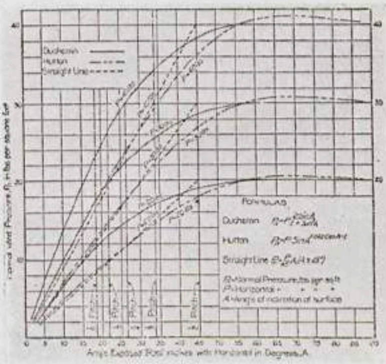


Fig. 26.

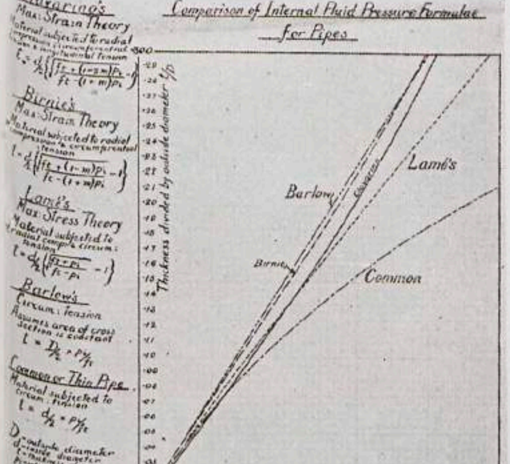


Fig. 27.

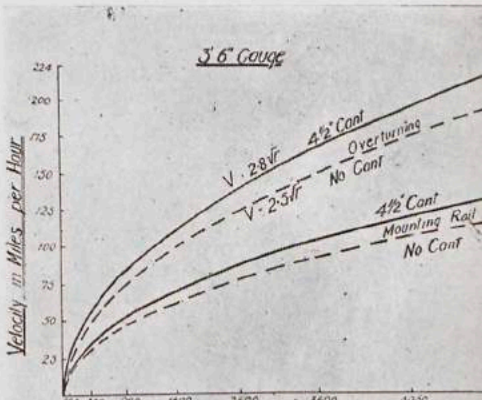


Fig. 28.

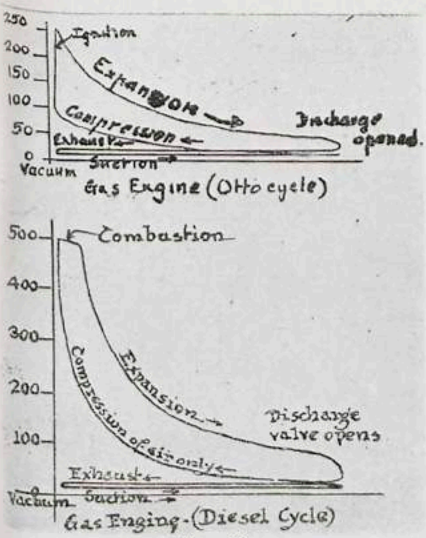


Fig. 23.

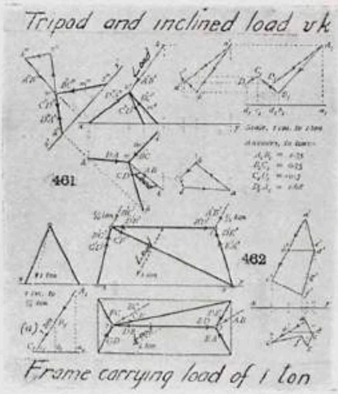


Fig. 25.

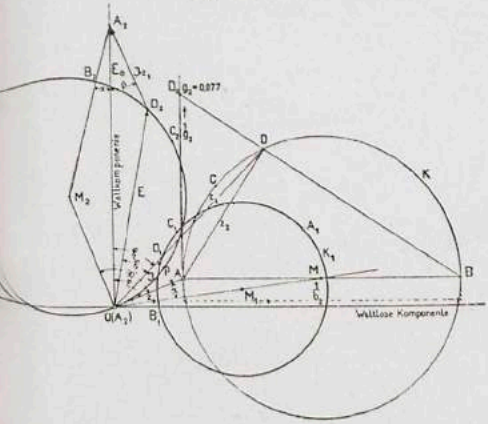


Fig. 24.

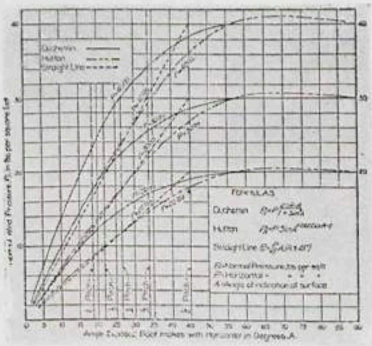


Fig. 26.

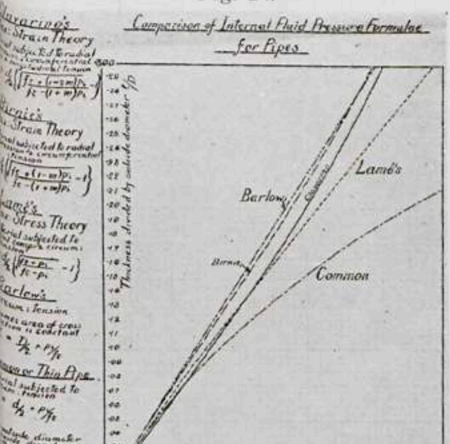


Fig. 27.

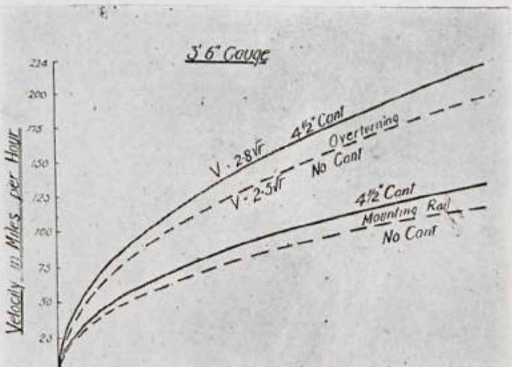


Fig. 28.

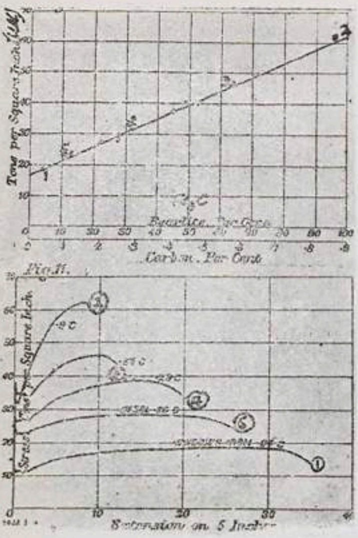


Fig. 29.

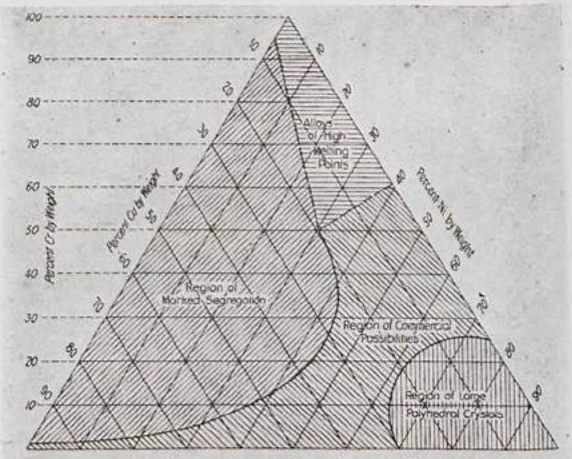
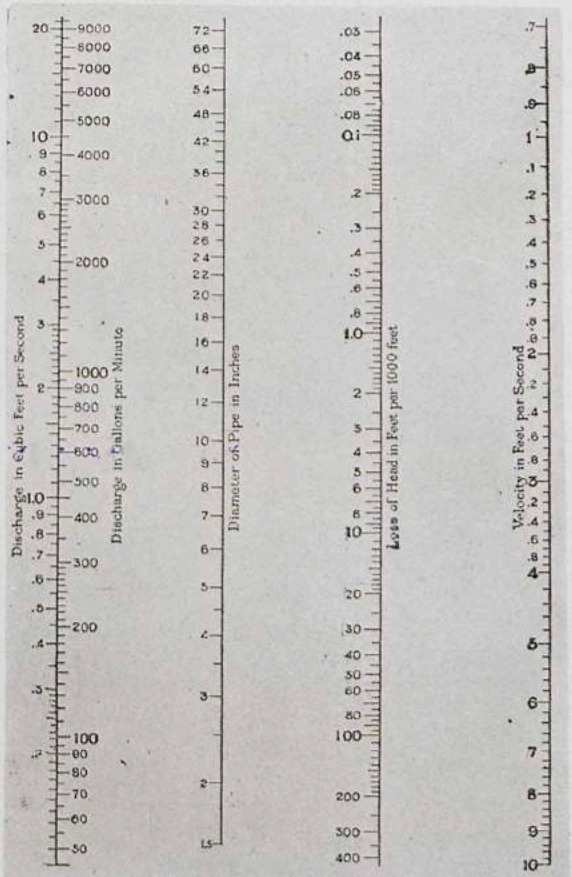


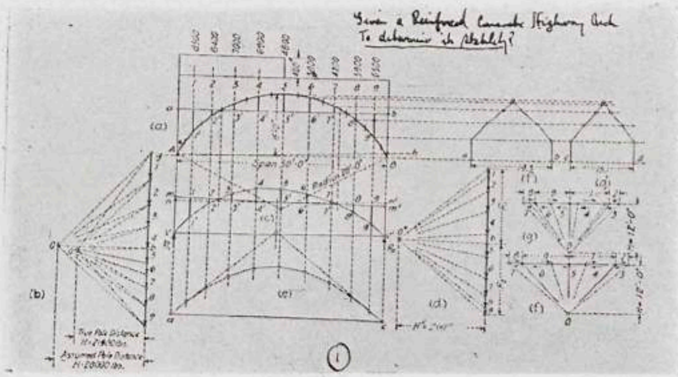
DIAGRAM SHOWING ALLOYS HAVING POSSIBLE COMMERCIAL VALUES.

Fig. 30.



—DIAGRAM FOR CALCULATING CAST-IRON PIPES.

Fig. 31.


Given a Reinforced Concrete Highway Arch
To determine its Stability?
True Pole Distance H=21900 lbs.
Assumed Pole Distance H=28000 lbs.
1

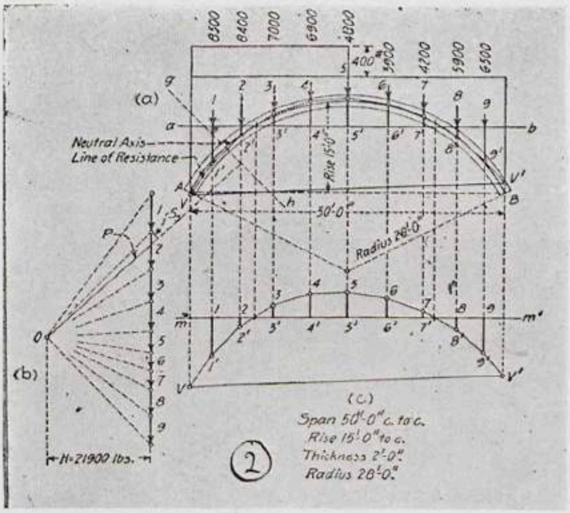

8500
8400
7000
6900
4800
400#
3900
4200
5900
6500
(a)
Neutral Axis
Line of Resistance
Rise 15'-0"
30'-0"
Radius 28'-0"
(b)
H=21900 lbs.
(c)
Span 50'-0" c. to c.
Rise 15'-0" to c.
Thickness 2'-0"
Radius 28'-0"
2

Fig. 32.

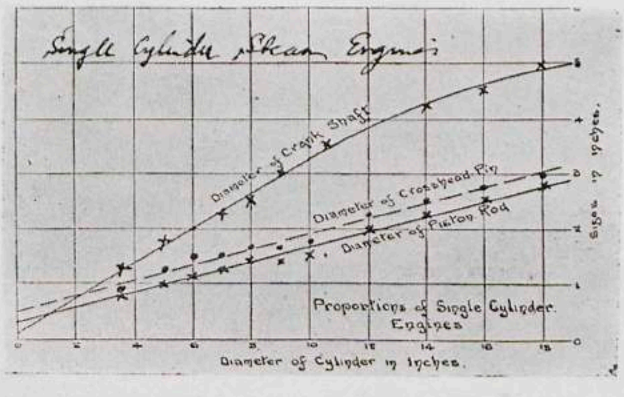

Single Cylinder Steam Engines
Diameter of Crank Shaft
Diameter of Crosshead Pin
Diameter of Piston Rod
Proportions of Single Cylinder Engines
Sizes in Inches
Diameter of Cylinder in Inches

Fig. 34.

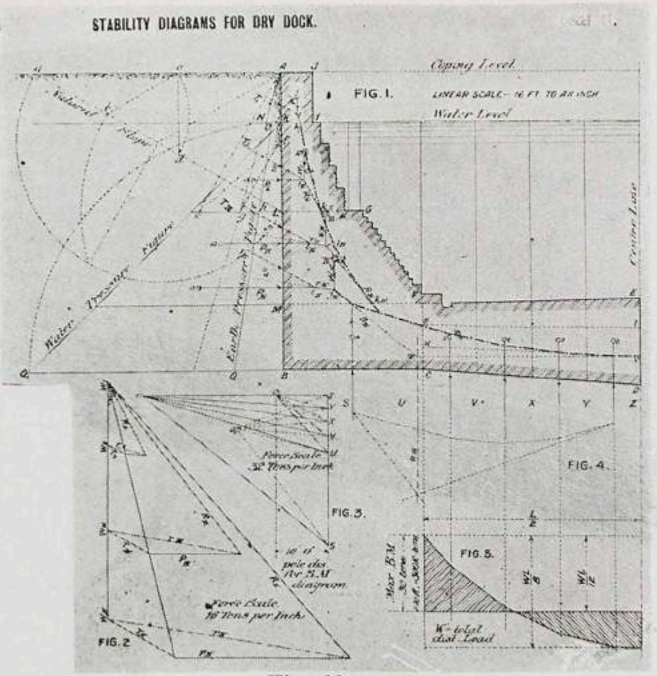
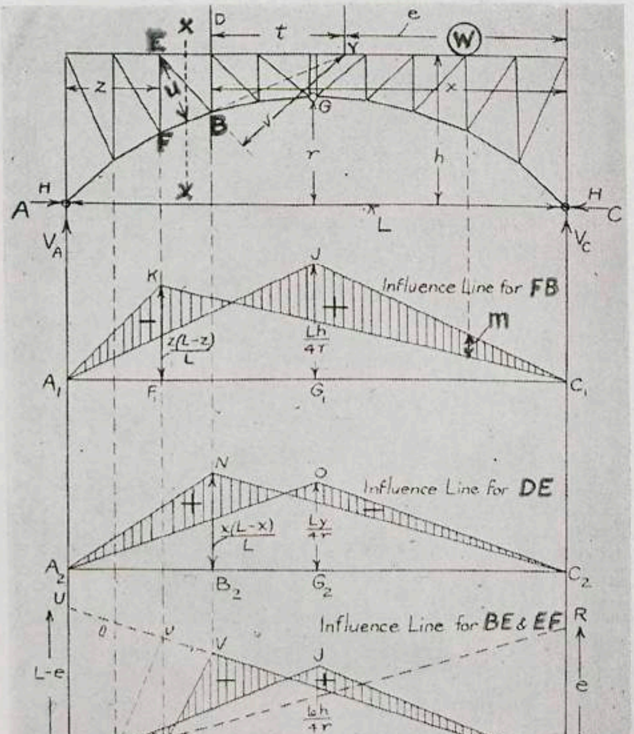
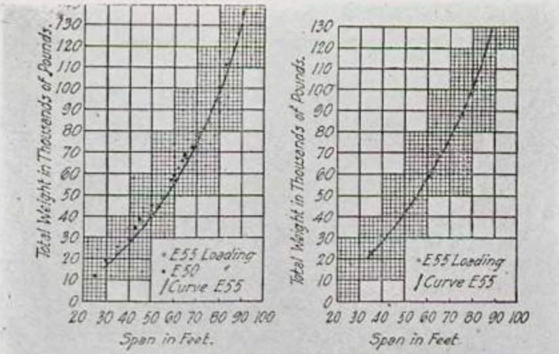


Fig. 33.



Influence Lines for three-pinned Spandril Arch.

Fig. 33a.



WEIGHT OF SINGLE TRACK DECK PLATE GIRDER SPANS. OPEN TIMBER FLOOR. TYPE A4 (FLANGES OF 6 ANGLES WITHOUT COVER PLATES). CHICAGO, MILWAUKEE & ST. PAUL RY.

WEIGHT OF SINGLE TRACK DECK PLATE GIRDER SPANS. TIMBER BALLAST FLOOR. TYPE A4 (FLANGES OF 6 ANGLES WITHOUT COVER PLATES). CHICAGO, MILWAUKEE & ST. PAUL RY.

Fig. 35.

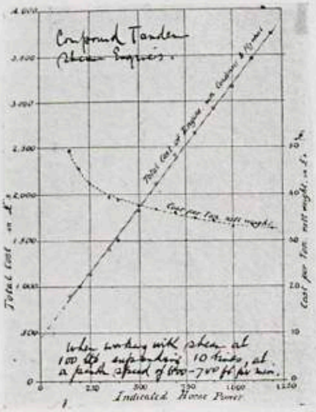


Fig. 36.

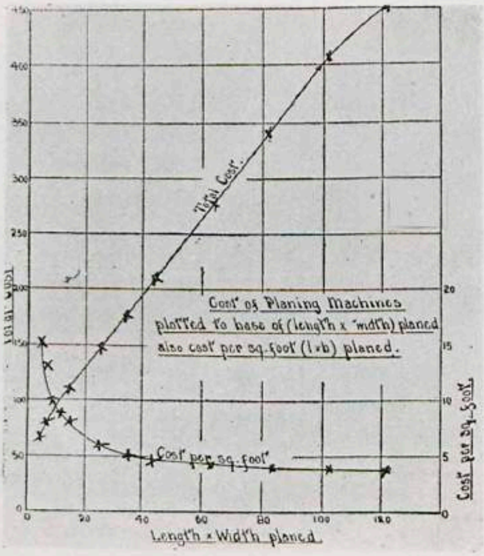


Fig. 37.

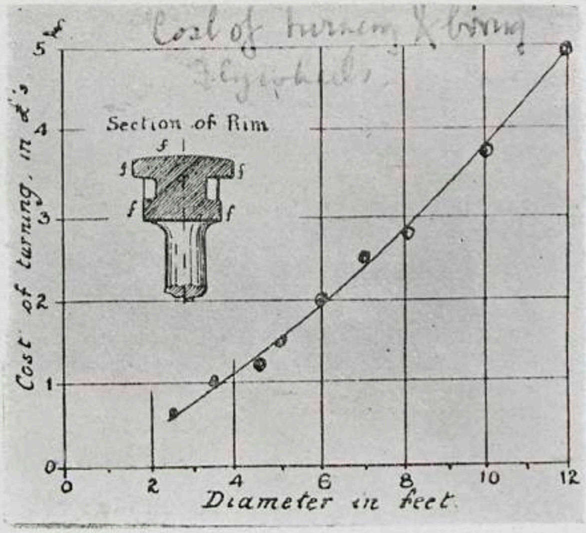


Fig. 38.

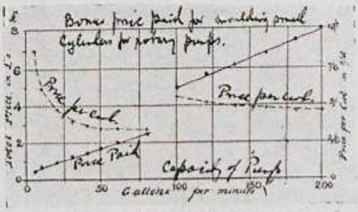


Fig. 39.

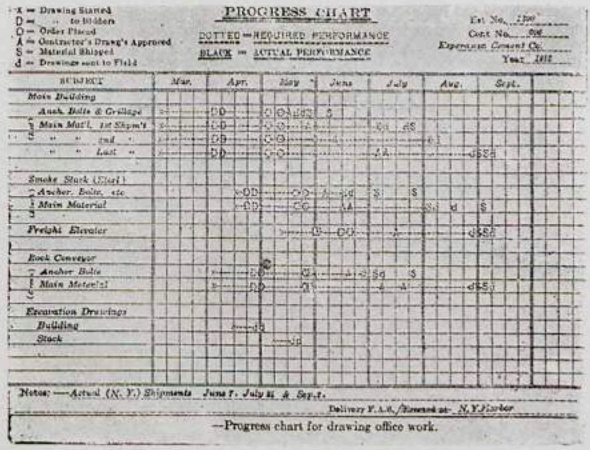
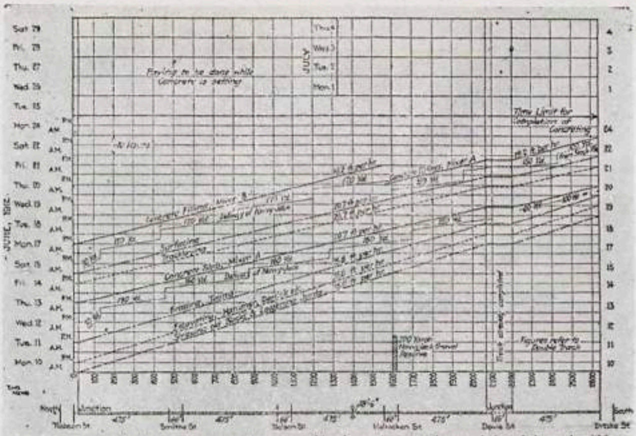


Fig. 40.



—Progress chart for track reconstruction; prepared in advance to ensure the completion of the work within a specified time. (Horizontal spaces from June 10 to 24 are ten-hour shifts.)

Fig. 41.

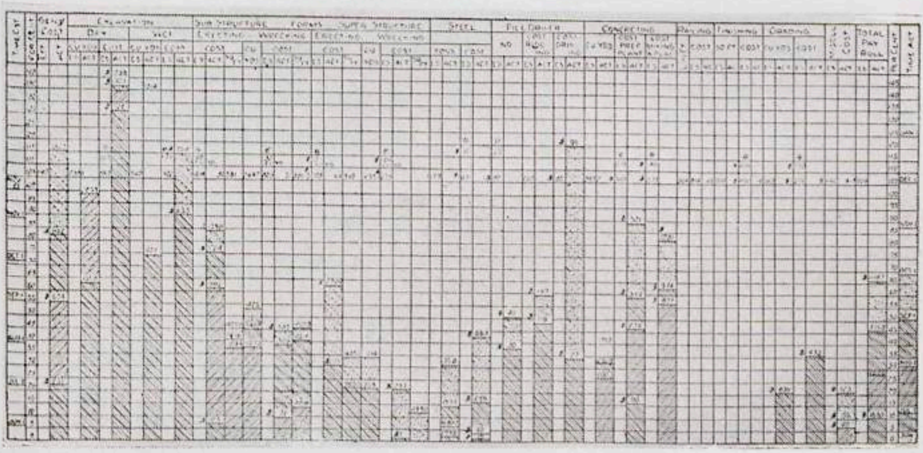


Chart showing expenditure for labor on construction job.

Fig. 42 (a).

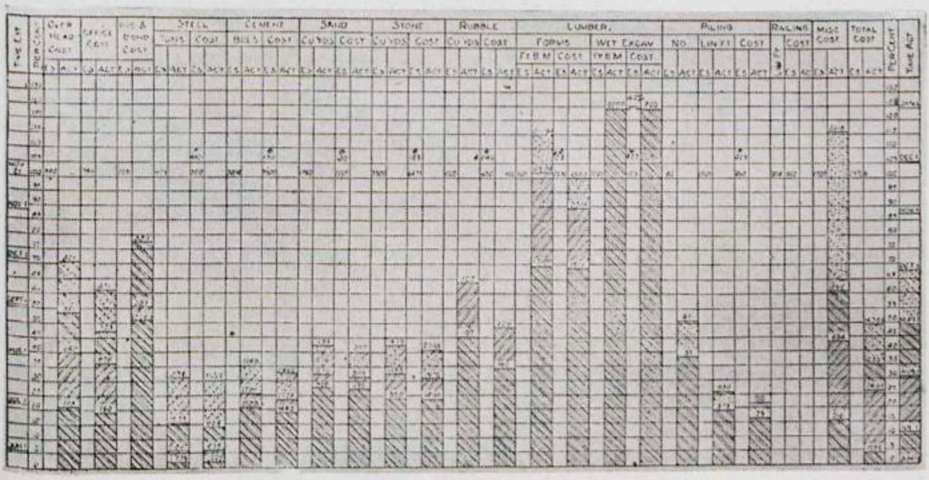


Chart showing expenditure for materials on construction cost-keeping.

Fig. 42 (b).

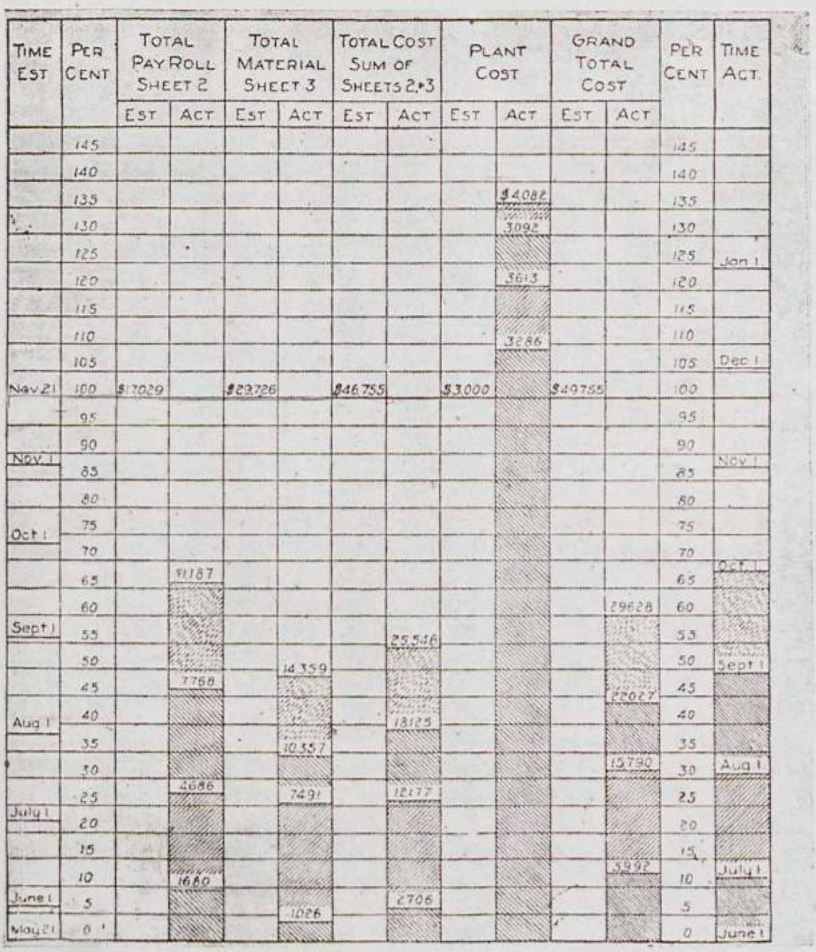


Chart giving summary of labor and material expenditure and plant cost on construction job.

Fig. 42 (c).

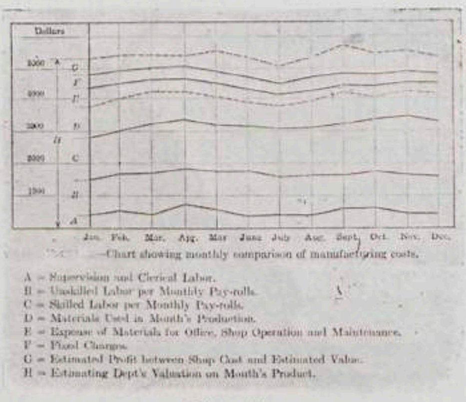


Fig. 43.

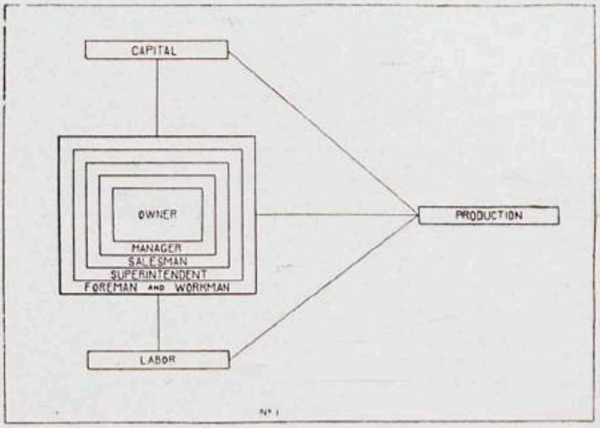


Fig. 44 (a).

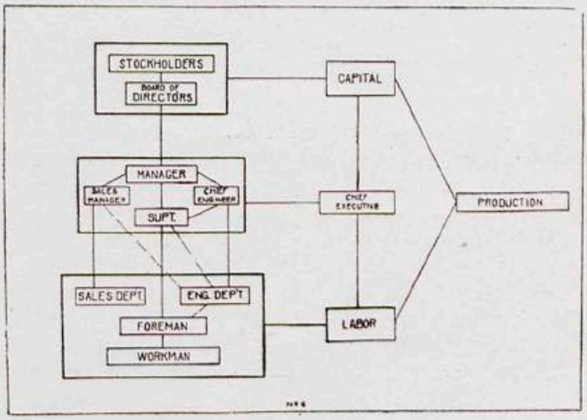


Fig. 44 (b).

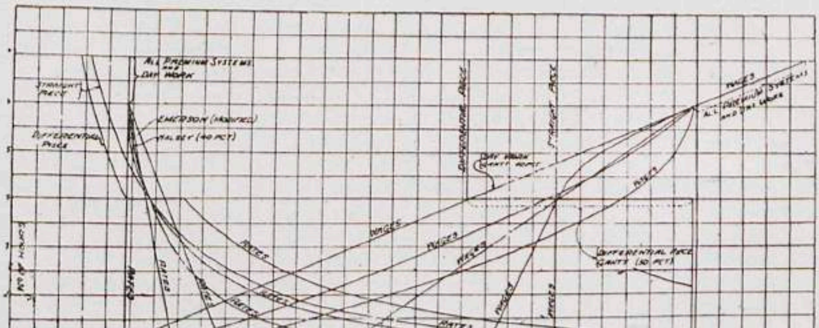
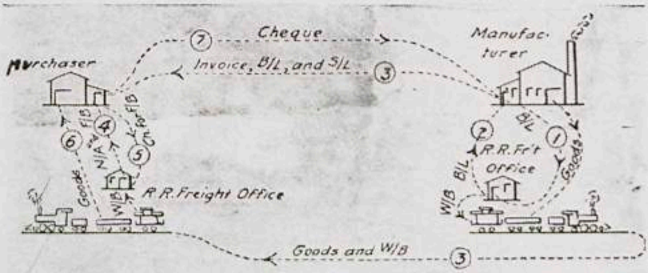
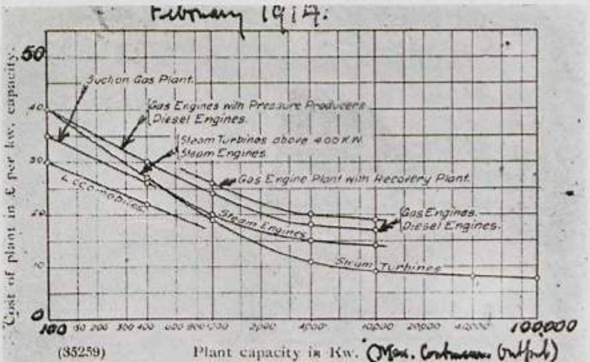


Fig. 45.



.—Diagram of procedure in domestic shipping.

Fig. 46.



Curves showing cost of power stations in £ per Kw. capacity, including electric generators, switchboard, building, foundations, cranes.

Fig. 47.

Western Australian Institution of Engineers.

(Incorporated)

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J. R. W. GARDAM, M.I.E.E., A.Am.I.E.E.
President 1918-19.

VOL. IX.

PROCEEDINGS—WESTERN AUSTRALIAN INSTITUTION OF ENGINEERS.
(Incorporated)

PAPERS AND DISCUSSIONS.

The Institution is not responsible, as a body, for the facts and opinions advanced in any of its publications.

GENERAL MEETING HELD AT THE INSTITUTION'S ROOMS ON 15TH MAY, 1918.

PRESIDENTIAL ADDRESS.

BY J. R. W. GARDAM.

In opening this session, I wish first of all to express my sincerest thanks to you for honouring me so highly by electing me your President, and I hope by giving the position every possible attention to maintain the dignity it has attained by the efforts of my predecessors in the chair, and I ask you all to help the objects for which this Institution was formed, by taking an active part in its proceedings and promoting its welfare.

We still find the whole world engaged in this agonising war, but the sorrows attending it will have been well endured if the enemy's claims to world domination are eternally vanquished. We look forward to the day when we can welcome back our splendid men, who have borne the hardships and dangers at the front that Australia may live.

Though the destruction during the war has been so appalling, we may, however, find some gleams of consolation in the awakening of British manufacturers to the possibilities of more efficient working and methods, the sharpening of the inventive faculties of those who have had by force of circumstances to meet unsuspected and immediate demands, the great lessons of how organisation can facilitate the handling of immense quantities of material and of men, and, above all, the urgent necessity of not only the Empire, but of Australia, being so

self-contained that never again shall we find ourselves dependent for many vital necessaries on foreign countries, that might at any moment become our enemies. The war has shown us our immense resources, most of which were hitherto neglected; it has drawn attention to the importance of scientific research; it has made us learn to make the most economical use of what we have; and it has emphasised the importance of the engineer both in war and in the peace to follow.

This Institution has a very valuable function to perform in bringing engineers into closer contact with one another, and we can benefit each other by discussing freely subjects of an engineering character, and by exchanging our experiences. To prepare a paper for reading before members causes us to study the subject anew and seek the latest information concerning it.

The time is opportune to unite with kindred societies throughout Australia in the formation of a Federal body to safeguard the interests of the profession and to give them their proper status in matters of national importance, and I sincerely hope the conference, to which we have sent two delegates, will find it possible to frame a constitution acceptable to all the participating bodies. We do not wish the proposed Institution to concern itself with trading problems, nor with wages or salaries disputes, nor to compete in any way with the work of the participating scientific and professional societies, but we want it to be able by the selection of the best men in the profession to speak as a body as truly representative of the whole engineering profession in Australia. The qualification for membership of the numerous societies very naturally differs considerably, but the Australian Institution will be in the position of admitting only the most qualified to full membership, and consequently to be a member of that body will be a hall-mark to one's status which will be as valuable as membership of the parent Institutions in Great Britain.

Our comparative isolation from the manufacturing countries has awakened us forcibly to our failure to make use of the profuse natural resources we have available. Though we have iron, lead, copper and tin in abundance, our local requirements were not met, but practically the whole was sent out of the country to be turned into manufactured goods. Until about a year ago not a sheet of copper was rolled, nor a copper tube drawn, for the very humiliating reason that the Germans had entire control of all the copper produced.

All this is being rapidly remedied, and industries are springing into existence, aided by the high prices now obtainable, which gives them good time to become well established before prices again become more normal.

The iron and steel requirements of the Commonwealth open up a large field for this industry, as in 1913 no less than 7½ million pounds' worth was imported, including about 150,000 tons of steel rails per annum, and £2,000,000 worth of plain and corrugated iron sheets.

At last the iron and steel industry is firmly established, and every praise is due to the courage and enterprise of men like Wm. Sandford, who erected the first blast furnace at Lithgow, N.S.W., some twelve years ago, which plant, surviving many troubles, is reaping the benefit to-day, and to the courage of the Broken Hill Proprietary Co., which has expended over 2½ millions on the steel works at Newcastle.

This Company is the fortunate owner of the richest iron ore deposit in the world, the average yield being 68 per cent. of metallic iron, while in England the ore averages about 30 per cent., in America from 50 to 55 per cent.; thus the superiority of the local ore is shown by the statement that 1½ tons of ore will produce a ton of pig, meaning a considerable saving in coal and flux, compared to the United States, Sweden and Russia, which require two tons of ore to the ton of pig iron, 2.4 tons in Great Britain and Germany, and about 2.7 tons in France and Belgium.

In addition, the Company owns lime-stone deposits in South Australia, and the steel works being built at Newcastle enables them to obtain unlimited supplies of coal.

The magnitude of the last mentioned works is indicated by their operations for the month of February, which showed that their blast furnace produced 10,534 tons pig iron. The open hearth furnaces, of which they have seven, produced 11,665 tons steel. The Blooming mill produced 10,660 tons steel ingots and the rail mill rolled 5,986 tons of rails and structural steel. Over 200 tons of 12 and 22 ft. plates, of varying thicknesses from ½ in. upwards, were rolled, and the 8-in., 12-in. and 18-in. Merchant mills produced 2,490 tons of light rails, bars and rods. An additional blast furnace is under construction, and the 78 coke ovens, which in February made 11,210 tons of coke, 115,062 gallons of tar and 135 tons of sulphate of ammonia, are being added to by 54 ovens, which will then make 300,000 tons of coke a year.

At the Melbourne works of Chas. Ruwolt, a side-blown converter (a modification of the Bessemer process) has been put down, which is capable of making steel castings ranging in weight from a pound or so up to 8 or 10 tons, and is turning out large quantities of castings for rolling stock, mining work, gearing, etc., of various classes; and in other parts several foundries are being established to carry out similar work.

Now that bloom and ingots can be obtained in any quality, this enables many manufacturing plants to produce the finished article, while iron and steel castings can now be turned out of any size.

Electrolytic copper has been produced in N.S.W. for many years, but now solid drawn tubes and copper sheets are being rolled, whilst large works have been built for drawing copper wire.

Corrugated iron is a commodity that has increased in cost five-fold since the beginning of the war, but now works are being erected to meet the demand.

Once the raw material is available in form suitable to the manufacturer, there is practically nothing of any engineering character that he cannot build, and in many respects this has been proved by the railway locomotives, stationary and marine engines of considerable size, steel ships, compressors, pumps, and even electrical machinery, which have been constructed.

While all this is practicable, given the material and the necessary skill, the matter of cost is secondary under present conditions, but this will not continue after the nations have returned to their saner pre-war occupations, and excessive tariff protection will not enable the high-wage go-slow policy of the unions to keep out competition. Good wages are essential to the welfare of the community, but the endeavour must be to devise machinery which will increase production to the greatest extent, and the workers must not hinder that realization. America has shown that high wages can be paid if unlimited production is permitted by the introduction of labour saving devices, but our labour leaders discourage production by limiting the number of machines a man may tend, by not allowing unskilled men to do unskilled work, by limiting the number of apprentices to an absurd figure. The Australian workman is as intelligent as any workman in the world, but he is not allowed to use his skill to the best advantage, and the labour leaders are ignorantly short-sighted if, as I understand, they hold the view that the less work a man does the more labour is required, for industries cannot be increased by these methods, whereas the more industries we have the greater the demand for labour.

What can be said of labour which is creating the present position? In the year 1917 there were 444 disputes, involving 1,941 establishments and 174,000 workers, who lost 4,689,316 days, representing £2,641,735 in wages, the most extensive dispute during the year being the obviously insincere objection to the card system. In ten years in N.S.W. wages increased more than 50 per cent., an average of from £97 to £147 per annum, while the number of able-bodied unemployed was in the last quarter of 1917 the worst on record.

While politics are rightly barred from our proceedings, I would point out that the initiation of new industries is receiving a severe setback by the War Time Profits Tax, which bears heavily on young or new industries and not at all on the concerns which made huge profits before the war. New industries are beset with other difficulties enough, and capital will not be forthcoming to assist them if sufficient profit is not allowed to be made to carry them over the attendant losses and the time to come when competition becomes keener.

The completion of the Transcontinental Railway between Kalgoorlie and Port Augusta is an epoch-marking event in this State's history, and while we have been a part of the Australian Commonwealth for seventeen years until this connecting link became a fact, separated as we were from the nearest State by four days' ocean travel, it was difficult to realise we were a part of the same great country. Since the official opening, however, which took place on November 12th, 1917, we feel in closer touch with our partners in the Commonwealth.

The line is 1,053 miles long, of which 454 are in Western Australia and 599 in South Australia, and though of engineering difficulties there were none, it was over five years after turning the first sod before the line was opened for traffic. The time taken in construction was lengthened by the frequent strikes of the men employed, though high wages and every consideration for their comfort was afforded them, and to delays in deliveries of supplies from overseas consequent on the war. The cost of construction, which was estimated at £4,045,000, has been considerably exceeded, and although the line has yet to be ballasted, the cost to date is 6½ millions. This is partly accounted for by large increases in the cost of materials and improvements on the original design, but more particularly is a condemnation of the day labour system.

At present the average speed attained is about 30 miles per hour, but when ballasting, which is now being proceeded with, is completed, an average speed of 44 miles per hour, including stops, will be attained; the time then occupied will be 24 hours between Kalgoorlie and Port Augusta.

Some of the conditions met with in the construction of this line were unique, and probably no similar length of railway in the world's history has been built where natural aids have been so absolutely lacking. In its entire length there are no permanent streams, and on a stretch of 840 miles there was only one known source of water supply; for nearly 800 miles the country was without a trace of settlement, and for 450 miles even firewood was unobtainable.

The absence of water along the route was one of the main obstacles, as probably no part has an average rainfall of as

much as ten inches per year, and for the most part the surface is so flat and the soil so absorbent that dam building would be of no use. Accordingly, dams have only been built for the first 150 miles at this end, and the first 250 miles at the Port Augusta end, and along these distances storage has been provided for 50 million gallons. Many bores and wells have been sunk along the line, but the quality of water in many of them was found unsuitable for locomotive use, while in one stretch of 150 miles every bore put down gave salt water, and in two places condensing has had to be resorted to.

The country through which the railway passes is unpromising. The first 167 miles from Kalgoorlie runs over a granitic plateau covered with salmon gum and other eucalypts and sandalwood, then for 450 miles is a limestone plain on which there is no vegetation but bluebush and saltbush, then follows the sandhill belt for 50 miles, after which to Port Augusta the country is varied and mostly well timbered with black oak, myall and eucalypts. The possibilities of the country traversed have yet to be discovered, but there is no doubt that the limestone country is suitable for cattle and sheep, while much wealth may ultimately be won from the auriferous belt at both ends of the line.

The Government electric power scheme should prove of the greatest assistance in promoting industries in and around Perth by providing cheap electrical power. It has now been in operation for over sixteen months, and has already reached a profit earning state. It was feared when started it might prove to be of too large capacity unless railway electrification was proceeded with, but by judiciously offering attractive rates to long-hour customers the load has risen to considerable dimensions, for with the present demand and what is already contracted for, the connected load will total 17,000 K.W., which will make a maximum demand on the station of 7,500 K.W., and consume approximately 17 million units per annum. This is made up of the following diverse loads:—Town lighting and power at Perth, Fremantle, Midland Junction, Guildford, West Guildford, North Fremantle and Cottesloe; tramways at Perth and Fremantle, flour-milling at Perth and Guildford, metal rolling at Perth, superphosphate works at West Guildford, engineering works at the Naval Base and Midland Junction, the wireless station at Applecross, the military camp at Blackboy Hill, the Greenmount Quarries, and the electric steel furnace at Midland Junction.

The scheme has proved itself eminently suited to its purpose, and though the periodicity of 40 cycles per second has been much criticised, while it is a convenient mean frequency technically for all purposes, the fact that it differs from the

standards in England and Australia renders all apparatus for its supply to be specially constructed for it, thereby increasing the cost, limiting the stocks available, and delaying deliveries, which are very serious objections and would have been obviated had the consulting engineers properly investigated local conditions before putting their ideas into effect to our disadvantage.

In view of the inception of an electric steel furnace in this State, members may be interested in a description of the method employed, together with some remarks on steel making in general.

Steel may be defined as purified pig iron which has been cast while in a molten state and in which the carbon and impurities in the original pig iron have been reduced. This is attained by oxidation, by dilution with a metal of lower carbon content, or by oxidation and dilution combined. Steel contains from .15 to 2.5 per cent. carbon, while pig iron contains from 2.5 to 5 per cent. In reducing ores in the blast furnace rough metals are obtained which contain many impurities, principally silicon, sulphur, phosphorus and manganese, and in the fining process these are eliminated by oxidation. In the open hearth process the carbon is reduced by mixing low carbon mixture with the pig iron, and in the Bessemer process by burning the carbon out of the pig iron. When the final stage is reached, spiegeleisen or ferro manganese are added. The affinity of manganese for iron is less than that of manganese for oxygen, and therefore manganese reduces the iron oxides by forming an oxide of manganese, which with silicious slag forms silicate of manganese, which remains in the slag and at the same time renders it more liquid.

The linings in either of the two processes may be acid, that is, silicious; or basic, that is, magnesia or other refractory material. In the basic furnace high phosphorus can be eliminated by adding lime, but in the acid furnace the silica lining would reduce the different phosphates in forming silicates going to the slag and phosphoric anhydride, which would remain in the bath and would be reduced by the carbon, thus the phosphorus would remain.

The open hearth process consists of a reverberatory furnace on the hearth of which is placed the pig iron and other materials to be melted, and the high temperature required is obtained by burning combustible gases produced in gas producers, in the furnace.

The Bessemer process consists of a converter, in which air is forced under pressure through the molten pig iron as it comes from the blast furnace, which oxidises the iron, forming oxides of iron, which are in turn reduced by the impurities to be removed.

The electric furnace economically produces the highest temperature obtainable, it gives positive control of temperature and time, it produces more steel in a given time than other methods owing to more rapid melting, it does not contaminate the charge through gases and other impurities as occurs in other systems, the metal is melted in a neutral or reducing atmosphere, and the refining can be carried to a very high degree. Whereas the open hearth and Bessemer processes are strictly limited, the electric furnace may produce steel equal to any of the other processes. While consideration must be given to the cost of doing so, for if only the cost of power is compared with the cost of fuel in the open hearth furnace, the electric furnace would not be commercially feasible and cannot compete with the blast furnace for smelting iron ores, but it is the best means of producing high quality steel and will produce steel as good as that made by the crucible process at a competitive cost.

It is stated that over 470 electric furnaces are already in use throughout the world. Of these, about 200 have been installed in America, producing annually 1,200,000 tons of steel, the largest furnace being at the Carnegie Steel Works, which is capable of working up to 30 tons, produces 6 heats of steel per 24 hours, and is said to consume only 175 K.W. hours per ton working on hot metal. In Canada there are 54 furnaces, producing 230,000 tons per annum, included in this being the largest electric steel plant in the world, producing 70,000 tons per annum.

There are many types of electric furnaces, comprising the Radiant Arc type, of which the Stassano furnace is typical, and which melts the metal by the heat radiated from the arc; the Arc Conduction type, of which the Heroult furnace is an example, in which the current passes from one electrode through the arc gap, along the surface of the metal, through the arc gap back to the other electrode, or the Girod furnace, in which the current passes from the electrode through the arc gap to the metal, thence to the conducting bottom of the furnace; the Induction type, as in the Kjellin furnace, where the metal bath is in the form of a ring, which is the short circuited secondary winding of a transformer embedded in the furnace itself; the Direct Resistance type, such as the Acheson furnace, in which the electrodes come into contact with the charge which forms the resistance; the Direct Radiation type, such as the Hoskins furnace, where the resistor is in contact with the crucible and heats the charges by direct radiation; and the Indirect Radiation type, such as the Bailey, where the resistor heats the charge by reflecting the heat from the enclosing walls on to the charge.

The one, however, that is now almost exclusively used for

steel making is the Arc Conduction type, and as it is of this type that the furnace being installed at Midland Junction is one of the most modern examples, I will briefly describe it.

The furnace is known as the Electro Metals or Gronwall type, and uses 2-phase current obtained from the 3-phase supply through the static transformers Scott connected. A separate phase is connected to the two electrodes, which passes through the roof of the furnace, where they are water-cooled. These electrodes are raised or lowered as requird by two motors connected to the gearing. The third electrode is situated below the basic lining and acts as a common return to the two phases. The current, therefore, flows from the transformers to the electrodes by copper leads, thence across the arc gap through the metal charge through the bottom lining to the bottom electrode and back to the transformers. The advantage of two phase working is that the circulation of the molten steel is improved, thus helping the refining action of the slag lying on the metal and distributing the heat evenly throughout the whole mass; it also is less severe on the supply system, as one arc may be interrupted without affecting the other, whereas in a single phase furnace the whole power would be cut off. This type of furnace is also preferable to the Heroult type, as the latter has the disadvantage of surface heating, which is undesirable, as the ferro alloys required in high quality steels sink to the bottom and accordingly do not melt so quickly.

The furnace itself is of steel plate construction and mounted on rocker castings, so that it can be tilted to draw off the slag or to run off the whole charge into the ladle, this gearing being actuated by a motor. The hearth is of basic refractory material and the walls and roof of highly refractory bricks. The steel frame of the roof is separate from the rest of the furnace, so that it can be quickly removed for renewal of the linings. Suitable doors are provided for charging the furnace and for running off the slag and product.

As the amount of current taken by the furnace is adjusted by raising or lowering the electrodes, it is usual in some of the larger furnaces to keep the current steady by actuating them by motors automatically controlled, but in the one to be erected here, which will have a capacity of 3 tons per charge, the electrodes will be operated by hand, as it is not considered that any advantage would be gained by automatically controlling them.

The usual practice in working an electric furnace is as follows:—

The charge, consisting of steel scrap, which may have practically any analysis, is placed on the hearth, the electrodes are then lowered and the current turned on. Pools of molten

metal soon appear round the electrodes, and an oxidizing flux of lime, sand and spar and either ore or mill scale is added, which, when the charge is entirely melted, takes up the phosphorus, forming phosphate of lime; the carbon, silicon and manganese in the scrap are oxidized and their oxides are dissolved, some of the sulphur is also oxidized and passes off as gas. The slag is then drawn off and a new purifying slag, consisting of lime spar and sand, is formed to recarburize the bath in order to give the required carbon to the steel and to deoxidize it, as it has become oxidized, due to the oxides of iron in the scrap and the oxidizing slag which was necessary to remove the phosphorus. As soon as the slag is formed carbon is added and the oxides of iron pass into the slag and the carbon reduces it. In this way the oxides are gradually removed from the whole of the metal; at the same time the sulphur is wholly removed from the metal into the slag. The steel is now ready for pouring, and such additions of alloys are made as are desired in the steel.

The pressure used during the melting period is about 80 volts, but as much less power is required during the refining process this is then reduced to 50 volts, resulting in less wear and tear on the furnace linings, the different pressures being obtained by connecting to suitable tappings on the transformers by means of interlocked switches.

The power taken by the furnace depends on the size and the degree of refining carried out, and varies from 600 to 900 kilowatt-hours, while the transformer capacity requires to be about 400 K.W. per ton below 3 tons capacity, 300 K.W. per ton up to 10 tons, and 200 to 300 K.W. above 10 tons.

The characteristics of electric steel due to its freedom from oxygen and its low phosphorus and sulphur contents are its freedom from segregation, blow holes and surface defects, and its great homogeneity. It is somewhat higher in tensile strength and elastic limit than other steels and shows a marked resistance to fatigue due to its greater density.

The Australian Electric Steel Company is to be congratulated on its enterprise in setting up the industry here, and it fully deserves the greatest measure of success.

In conclusion, I trust the brilliant opportunities opening up for engineers will be availed of by them, and that each by his zeal and enthusiasm for his profession will merit the confidence he is entitled to.

(10th July, 1918.)

ENGINEERING PROBLEMS IN ANCIENT AND MODERN GUNNERY.

By Professor A. D. Ross.

Until the fourteenth century war engines were almost entirely weapons designed upon the principle of the sling. Thus we have the *catapultae* and *balistae* of the ancient Romans, the former machines discharging darts and the latter heavy stones. In more modern times we find the *trébuchet* of the French—a beam sling for hurling stones, incendiary materials, or putrefying carcases—a machine which survived the introduction of artillery.

The invention of gunpowder, however, revolutionised the art of warfare. It has been commonly said that gunpowder was known to the ancient Chinese, but recent investigations have disproved this. The Chinese certainly knew of various incendiary compositions, but their knowledge of gunpowder was acquired only in the fourteenth century through information transmitted from Europe. There seems reason to believe that the discovery of gunpowder was made in the thirteenth century by Roger Bacon, and Colonel Hime, who has given careful attention to the subject, has produced much evidence in support of the contention.

The first guns were constructed early in the fourteenth century. A record of the City of Ghent dated 1313 refers to the recent discovery of *bussen*, and subsequent entries refer to the dispatch of bussen and gunpowder to England. As the term bussen had then been long in use to denote hand grenades, it is apparent that the word was used in a new sense, and probably indicated a rudimentary gun. Certainly we have clear evidence from a picture dated 1327 in Christ Church Library, Oxford, that guns of vase form were then in use for throwing huge metal darts.

Flanders soon became the centre of gun manufacture. While no guns were used at Bannockburn in 1314, nor at Berwick in 1318, they were—according to Froissart—used on the Continent of Europe in 1338-9, and in particular they were used at Crecy in 1346.

The early cannon or bombards were built of forged iron bars or staves running longitudinally, and were bound together by wrought iron hoops. The hoops were shrunk on, but could have given only very limited strength against the radial and hoop stresses on firing. Indeed, it is remarkable that guns of moderate size were made and used, although built up merely

after the manner of a cask. The famous Mons Meg, manufactured about the middle of the fifteenth century, was a gun built on this principle. This remarkable piece of ordnance had a 20-inch bore over 9 feet long, and weighed nearly 9 tons. Using a charge of about a hundredweight of gunpowder, she threw a 549-lb. stone ball nearly 5,000 yards, or a half ton iron ball over 1,400 yards. The gun was used on many occasions, and although her active life ended in 1680, she is still in existence at Edinburgh Castle.

Early ordnance were mostly breech loaders, and the closing of the powder chamber was often effected by iron wedges—a crude and inefficient method which must have made guns as dangerous to the gunners as to the enemy. Elevation was secured in a very rough manner by fixing the gun in a wooden cradle, which was elevated between upright posts provided with holes and pins like an easel. The most remarkable feature of these guns was that no provision was made for recoil. The gun was firmly banked up, and so being unable to give to the shock of discharge, was subjected to terrific strain. About the middle of the fifteenth century trunnions were introduced to allow of elevation by putting a wedge below the breech, supported by a transom. The trunnions being about the middle of the gun, conveyed the shock of firing through the trunnion bearings to the cheeks of the gun carriage, and thus to the trail. This development therefore resulted in the abandonment of the old absurd system of banking up the gun behind.

In the sixteenth century bronze guns became common, and at a much later date cast iron guns were used. To withstand the high pressures developed in modern guns, a low carbon nickel-chrome steel is now employed, the material being hard and highly elastic and tenacious. These guns are invariably built-up guns, consisting of several tubes, and—in the case of British guns—with steel ribbon reinforcement. Let us consider the advantage of such construction. Take the case of a single cylindrical tube with thick walls subjected to internal pressure. At each point of the material the stress has three components, viz., a radial stress, a tangential or hoop stress, and a longitudinal stress. If the metal were initially unstrained, at the time of firing, the first component stress would be compressive, and the two latter components extensive. In point of fact, the longitudinal stress is small compared with either the radial or the tangential stress, so we need concern ourselves only with the two latter components. It is evident that the stress at any point in the cylindrical wall is balanced partly by the resistance to stress of the material at that point and partly by the support received from the material to the outside of it. The stresses, therefore, are greatest at the inner and least at the outer surface.

Fig. 1 shows the component radial (R_0) and tangential (T_0) stresses in a gun tube, one calibre thick in its walls, when a gas pressure of 16 tons per square inch is developed inside.

FIG 1

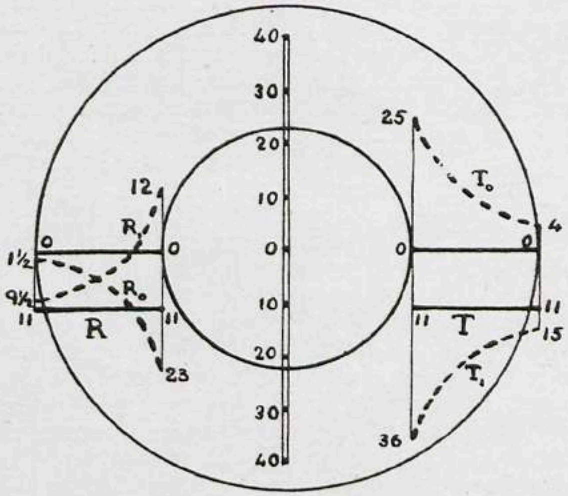
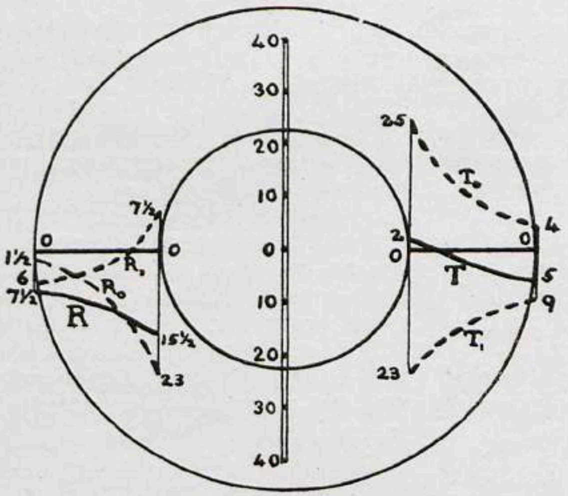


FIG 2



RADIAL AND TANGENTIAL STRESSES.

The magnitude of the stress at various points in the thick wall is indicated by the distance of the graph from the horizontal radial line, OO. For extensive stress the graph is above the zero line and for compressive stress below. The scale of stress in tons per square inch is given on the central vertical line of the diagram, and is the same for the radial stresses shown on the left-hand side of the diagram and for the tangential or hoop stresses shown on the right-hand side. (Note that the intensity and distribution of the stresses at points in the walls of such a gun tube depends only upon the pressure applied and the thickness of the wall measured in calibres, and does not depend upon the absolute calibre. Thus the stress intensity and distribution would be the same for the same internal pressure in an 8- and a 12-inch gun tube if the thicknesses of the walls were 2 inches and 3 inches respectively.) The curve R_0 shows that the radial compressional stress varies from 23 tons at the inner surface to 1½ tons at the outer, while the curve T_0 shows that the hoop extensional stress varies from over 25 tons to 4 tons. Curves R_1 and T_1 show the values of the same component stresses when the tube is subjected to zero internal pressure and a 16-ton external pressure. R_1 varies from an extensional stress of 12 tons at the inner surface to a compressional stress of 9½ tons at the outer surface, while T_1 is a compressional stress varying from 36 to 15 tons. If the tube were subjected simultaneously to the internal and external pressures, the two component stresses would each be an 11-ton compressional stress at all points in the wall, as shown by the straight line graphs R and T.

Fig. 2 shows in similar manner the individual resultant component stresses when the internal pressure is 16 tons and the external pressure 10 tons.

From the figures it is evident that the application of external pressure greatly diminishes the stress produced by internal pressure. Thus if the material had elastic limits 25 and 36 tons for tensile and compressive stress, it would be strained to the utmost limit by an internal pressure of 16 tons acting alone. But it would never be stressed beyond about 60 per cent. of the limiting stress if subjected to a constant 10-ton external pressure and an intermittent 16-ton internal pressure. The curves also show by their form that no considerable gain would be achieved by increasing the wall thickness beyond one calibre. Indeed, a tube one calibre thick has about 85 per cent. of the strength of a tube of infinite thickness.

In the manufacture of guns the external pressure on the innermost ("A" inner) tube is obtained by shrinking on another ("A") tube. In designing the gun, care must be

taken that no part is strained beyond its elastic limit when the gun is either at rest or in action. The greatest advantage will be obtained from a compound system of shrunk on tubes when each tube is brought simultaneously to the elastic limit by the same internal pressure in the innermost tube. If the outer tube were strained to the elastic limit before the inner tube, we could not take advantage of the full strength of the inner tube, while if the inner tube were strained to the elastic limit before the outer tube we could not take full advantage of the strength of the outer tube. It can be shown that, in a compound gun whose tubes are of similar elastic properties, it is impossible to arrange for the innermost tube to be compressed to the elastic limit at rest and each tube strained to the elastic limit in action unless at least four tubes are employed. In practice large guns built wholly of steel forgings are made of three or four tubes, according to their size and power.

Figs. 1 and 2 show that gun tubes always experience the maximum stress at the inner surface, and hence full advantage is not taken of the strength of the outer parts of the tube. We can therefore increase the resultant strength for the same weight of metal by using more and thinner walled tubes, or we can obtain the same resultant strength with more tubes and less weight of material. This is partly the reason why the British Government in 1890 adopted the system of wire-wound guns. A wire-wound gun is—roughly speaking—a gun built up of a large number of concentric tubes. But ribbon steel has, in addition, fully double the strength of steel forgings, the material is less liable to flaws, it permits of fine adjustment of the reinforcement, and ruptures are generally confined to one of the many coils employed. Wire-wound guns have naturally less longitudinal strength, but as already pointed out, this is not so important. The British naval gun consists of an "A" inner rifled tube with an "A" tube shrunk on; wire ribbon is wound on this tube and is enclosed in a "B" tube, which in turn is enclosed in the jacket tube. For a 12-inch gun, the "A" inner tube has walls over $2\frac{1}{2}$ inches thick; the "A" tube is 3 inches thick; some 100 miles of steel ribbon $\frac{1}{4} \times$ 1-16 inch are wound on at a tension ranging up to nearly 50 tons per square inch, the number of layers varying from about 12 at the muzzle end to 70 or 80 at the breech end of the winding. The outer tube has walls about 2 1-3 inches thick.

Pressures up to 20 tons per square inch are being employed in the firing of naval guns, and it seems unlikely that that will be exceeded unless some altogether new material for gun construction is devised in the future. How then have the Germans been able to shell Paris from a distance of over 70 miles? Methods which might suggest themselves would be : (i) a more constant pressure during the passage of the shell down the

gun, (ii) a compound shell, (iii) a sub-calibre shell, (iv) a very long gun. Let us consider these briefly.

1. It is very unlikely that a powder can be designed which will burn at such an increasing rate as will well maintain the maximum allowable pressure during the whole process of discharge of the shell. The successive ignition of a series of charges has proved unworkable.*

2. A shell which will disrupt in its passage through the air so as to send on one portion with greater speed could not give the requisite gyrostatic stability nor the required accuracy of direction to the quickly moving part.

3. A sub-calibre shell offers similar difficulties. Its base must fit the gun tube to obtain the full driving thrust, but owing to the small mass and small radius of the remainder a very high rotational speed would be required to provide sufficient gyrostatic stability.

4. A very long gun appears the simplest solution, provided a powder burning at the necessary rate can be obtained. By a very long gun one means a gun exceeding 50 calibres: it might be either of small diameter and of length equal to our longest guns, or of large diameter and exceptional length.† If the shell is about 9 inches diameter the gun would probably be about 100 calibre, giving to a shell weighing 300 lbs. an initial speed of 5,000 feet per second, which would suffice for the range, especially as the trajectory would rise to a height of over 20 miles, where the atmospheric density and consequent resistance would be very small.

It is interesting to note the enormous difficulty of using artillery at such a long range. Apart from the usual allowances in laying the gun for air temperature and density, wind, jump, and drift, one would require to make considerable allowance for the curvature of the earth and for the earth's rotation. Drift, as explained in a previous paper,‡ is a somewhat uncertain quantity, and this is especially true with long range, high velocities, and projectiles of comparative small mass and radius. In the case of firing on Paris, it would probably run into miles, while the earth's rotation during the $2\frac{1}{2}$ minutes flight of the shell would cause a further drift of more than half a mile.

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* Tried in the Lyman Haskell gun of 1881.

† Note added January, 1919. The latest reports indicate that the first of these alternatives is the more probable. The gun is very possibly a 15-inch 50 or 60 calibre gun, which has been lined with a 9-inch tube, making the gun a 100-calibre type.

‡ Proc. W.A. Inst. Eng., vol. VII, p. 18, 1917.

(7th August, 1918.)

THE EVOLUTION OF COINING MACHINERY.

By A. Ventris.

The use of coins can be traced back to the 8th Century B.C.; spherical blanks were cast and marked with a die, which was struck by a hammer on a small anvil. The anvil was, at a later period, marked with various designs, and thus became a reverse die. The casting of the blanks into lenticular shapes was a subsequent improvement.

In the Middle Ages plates of metal were cast, hammered out upon an anvil, and cut into pieces by shears; these pieces were annealed, hammered and clipped, and by further annealing, flattening, clipping and gradual rounding, blanks of the desired size and weight were obtained. The edges of the blanks were finished by being tapped with a light hammer. The discs were then annealed, pickled and dried, preparatory to coining, for which operation two engraved puncheons or matrices were used, one called the "pile," the other the "truss." The pile bore the coat-of-arms or reverse, the truss the effigy. The pile was about eight inches in length and had a kind of collar forged on it beneath the engraved portion, from which point it was rapidly tapered, so that it could be driven into a block of wood, the collar taking a bearing upon the surface of the block. The coiner placed the blank on the pile and superimposed the truss, which he held steadily in his left hand; he then gave several smart blows on the truss with a hammer held in his right hand. If, after examination, the piece was found to be imperfectly stamped, it was replaced between the dies in exactly its previous position and the blows were repeated until the piece was properly coined. In order to minimise the concussion it was customary to wind a strip of sheet lead around the truss, and in later times, when large coins were made and heavier blows became necessary, the truss was held by a twisted hazel stick in the hands of a second man. (See Fig. 1.)

About the year 1553 coinage by the "mill" was introduced into the Paris mint. Similar machinery was first used in England in 1561, but it did not finally displace coinage by the hammer until the year 1662, and from that date until 1816 few improvements were effected. For coinage by the "mill" the cast plates or bars were scraped and cleaned, and then passed through a rolling mill, worked either by manual or horse-power, in order to bring the resulting strips to the exact thickness of the blanks required—annealing when the metal showed indications of hardness. Blanks were then cut out by means of a machine whose working parts consisted of a punch

attached to an arbor, the upper portion of which was formed into a screw, which, when turned a portion of a revolution by an iron lever, gave the requisite power when the cutter was brought down upon the strip of metal. The discs were then weighed upon a fine balance, the light pieces were re-melted, and the heavy ones filed to the correct weight. They were then blanched or pickled.

Fig. 1.

The next process was the graining of the edge of the blanks. The machine used for this purpose consisted of two plates of steel 1/12th of an inch in thickness, on which the legend or graining was engraved, half on each strip. One of these plates was screwed to a copper plate and that in its turn was screwed to a table; the other strip was movable on the copper plate and had a rack attachment which engaged in a pinion fitted on a spindle carried in a bearing. A handle was fixed on the spindle, and when the sliding plate was adjusted parallel to the fixed plate and a blank placed between the two, a half turn given to the handle would transfer the inscription to the blank. The pieces were then annealed, preparatory to coining. The coining press was the forerunner of the well-known fly-press. The beam was a long iron bar with a heavy ball of lead at each end, and had rings to which cords or straps were fastened. The screw, fitted centrally in the beam, passed through a nut in the framing, and its lower end was cupped into a guided arbor in which the reverse die was fixed. The obverse or head die was placed immediately beneath in a small case fixed to the foundation of the press. The blank was placed on the lower die, then two men hauled on the cords, revolving the screw rapidly downwards and causing the upper die to meet the blank

and convert it into a coin. The force of the blow would be regulated by the number of turns given to the screw. In an old engraving (see Fig. 2) of the mint in the Tower of London the coining presses are seen worked by levers instead of cords, and it can be assumed that that method was the latest improvement prior to the employment of steam-power in the new London Mint, the erection of which was commenced in 1810.

Fig. 2.

The firm of Boulton and Watt, Birmingham, is credited with the invention of coining machinery actuated by steam power in 1788, and machinery for the new mint was supplied by that firm and brought into use in 1816. The plant consisted of six sets of rolling mills, four of which had their bottom rolls revolving in fixed bearings, the upper rolls being in guided bearings, beneath which were supporting rods continued beneath the floor to the short ends of pivotted levers, which were sufficiently weighted at the long ends to keep the upper side of the bearings pressed against the ends of powerful screws in the framings. These screws were bridged across at their upper ends and a rack and pinion arrangement enabled the rolls to be raised or lowered. A powerful pair of shears was also provided. The remaining mills had fixed bearings for the upper rolls and movable bearings for the lower rolls, a pair of wedges provided with screws and mitre-wheel gearing enabling adjustments to be made in the thickness of the fillets within 1/1000th of an inch. A punch for cutting out trial blanks and a balance for weighing them completed the rolling equipment.

In 1816 a machine was introduced into the London Mint by Sir John Barton for equalizing the thickness of fillets after rolling. A bar of metal during the operation of rolling is

extended materially in length and but slightly in width, but the centre offering greater resistance to lamination than the edges, is always the thicker. This appliance is constructed after the lines of a pipe-drawing machine, but instead of having hollow dies in the head, it has two very accurately hardened and ground fixed steel cylinders, between which the fillet is drawn, sufficient pressure being maintained upon the upper cylinder to transfer the excess metal from the centre of the fillet towards the edges.

In order to introduce the end of the fillet between the cylinders a flatting mill is made use of. This consists of a pair of small rollers adjusted to give the desired thickness, driven in opposite directions by geared wheels. The upper roller has three flat surfaces, so that when the end of the fillet is placed upon the lower roller between a flat the continued revolution will compress and eject the two inches or so of the fillet presented to it, enabling it to be passed between the cylinders of the drag-bench and projecting beyond them far enough for the jaws of the "dog" to grip it. The "dog," mounted on four wheels, runs the length of the bench and has claws which connect with one or other of the links on an endless chain, and become disconnected when the fillet has been pulled through.

The cutting out machinery (see Fig. 3) supplied by Boulton and Watt was very ingenious. Circular in form, it was placed in a circular room 30 ft. in diameter. Twelve cutting presses were spaced 3 ft. 6 in. apart around the outer circumference

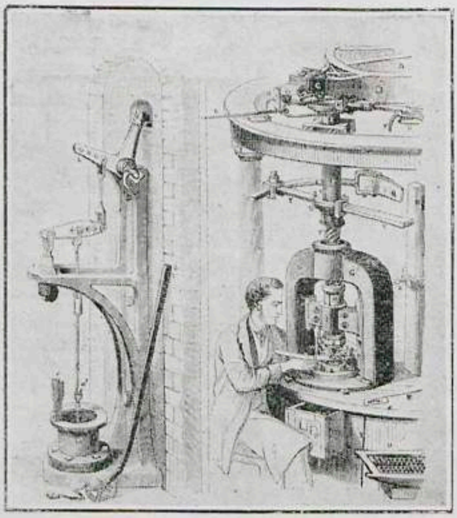

Fig. 3.

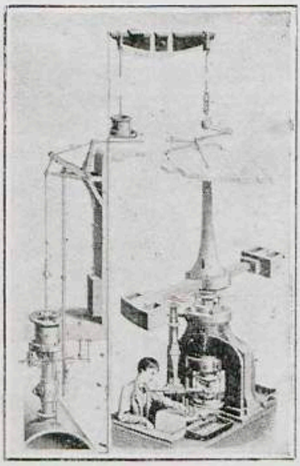

Fig. 4.

of a platform raised 16 in. from the ground and 21 in. wide. Twelve cast-iron columns 3 ft. 6 in. high, spaced 3 ft. 6 in. apart, supported a circular iron cornice 5 in. deep. In the centre of this enclosure revolved an 8 in. vertical shaft carrying a cam-wheel 9 ft. 6 in. in diameter and 10 in. deep, with 12 cams, each projecting 14 in. and being 28 in. in length. Immediately above it was a flywheel 18 ft. in diameter, with a rim 14 in. wide by 3 in. deep. I may perhaps be pardoned for entering into so much detail, because this remarkable mechanical invention was destroyed in 1883, when a new type of machine was introduced into the London Mint. The press screw of each machine was fitted into a hollow shaft with gearing for connecting it with a continuation shaft taken through a bearing attached to the inside of the cornice, and carried at its upper end a lever with a friction-roller. The cam-wheel in its revolution struck the friction-roller and threw it outwards, communicating an upward motion to the screw of the cutting press and raising the cutter ready for use. As the weight of the descending screw would be insufficient in itself to cut out a blank, when the cam, after its passage over the roller, had permitted it to fall, atmospheric pressure was utilized. The roller-lever was provided with an iron loop, and by a series of rods and levers was connected with a well-fitting piston working in an open top cylinder affixed to a stone slab outside the wall of the cutting-room. As a safeguard against air leakage, the surface of the piston was covered with an inch or two of oil. The raising of the piston, therefore, produced a vacuum in the cylinder and after the cam had passed its friction-roller the pressure of the air upon the surface of the oil above the piston violently pulled back the roller-lever by means of its connecting rods and brought the cutter down upon the strip of metal being operated upon, removing a disc, which fell through a bolster into a box beneath. On the shaft under the cornice a lever fitted with an adjustable arm carrying a wooden wedge struck a veritcal spring-piece, after cutting a blank, throwing back the press screw into its starting position. A pedal attached to a cord connected with a spring near the upper lever had to be depressed to keep the machine acting; when the pedal was raised the spring prevented the friction roller from coming into contact with the revolving cams.

The machinery supplied for coining (see Fig. 4) was somewhat similar to that of the cutting presses, but as the pressure required for this purpose is vastly greater than that needed for cutting, a chamber or pipe kept in a constant state of partial exhaustion by means of an air pump was used instead of vacuum cylinders.

The eight presses were mounted on a platform 2 ft. 6 in. from the ground, were of the screw type, and automatic. The

fly-shaft was 6 ft. in length and had heavy cast iron weights at the ends. A trumpet shaped hollow shaft attached to the top of the fly-shaft and revolving with it was traversed by a rod passing into a room overhead. This rod was fixed at its lower end to the top of the press screw and at the other end to a swivel, thence by another rod to the end of a balanced beam, the opposite end of the beam being connected with a piston working in a small open-top cylinder having a pipe connection with the vacuum chamber. This arrangement permitted the regulation of the power of the blow by means of a cock on the connecting pipe. A lever was fixed on the top of the trumpet shaft and was connected by rods to a rocking frame fixed on the outside of the wall behind the presses. Connecting rods from the rocking-frame linked up a piston working in an open-top cylinder with a pipe connection to the vacuum chamber beneath it. The press was started by the coiner pulling a cord in the box where he sat; this action released a lever operating a valve in the bottom of the cylinder and allowed it to act when called upon. A second cord was then pulled, which by means of its lever opened another valve and permitted the atmosphere to rush in from the bottom of the cylinder piston and through the connecting pipe into the main vacuum chamber. This reduced the pressure upon the lower side of the piston, and the normal atmospheric pressure upon its upper face compelled its descent. A wooden rod with tappets arranged so as to strike the levers of the two valves at the right times was suspended from the rocking-frame, and so gave continuous motion to the press.

The method of supplying blanks to the press was as follows:—A tube kept filled by the coiner was situated over a slide, worked backwards and forwards by a pivotted lever, the upper end of which obtained motion from a link attached to the screw-shaft. The lowest piece in the tube was seized between two fingers, one of which was fixed, the other pivotted. Assuming the upper die to be at its highest position, the piece would be carried forward and held immediately over the lower die. The movement of the screw downwards caused the blank to drop upon the lower die, the collar (milled, plain or lettered) rising at the same instant to receive it. The collar on the neck of the lower die had a spring underneath, while above it a frame with lugs right and left received the ends of two rods passing through the shoulders of the press; so that when the lugs were depressed by the movement of the screw downwards, the spring ensured the rapid rise of the collar. The continued movement brought the upper die down upon the blank, after which the collar would fall and the coined piece would be pushed off the die by the fixed end of the slide, which was at the same time conveying between its fingers another blank to

be struck. The two above-mentioned rods also prevented any twisting motion being conveyed from the screw, which was cupped into the block carrying the upper die.

The London Mint discarded these comparatively slow-working presses in 1882, but identical machinery is still working in Calcutta and Bombay.

From earliest times until the year 1843 coins or blanks were individually weighed by small hand balances. In that year William Cotton, the Deputy-Governor of the Bank of England, introduced a machine for automatically weighing gold coins and separating the light from the good. A function of the Bank of England is the weighing of all British gold coins received by it, and no coin is re-issued unless it is of current weight. Gold and silver coins have not only a definite weight fixed by the laws of the countries issuing them, but they also have what is known as a remedy allowance or tolerance above and below that weight. Thus, the sovereign when issued should weigh 123.274 grains, with a tolerance of .2 of a grain. It is not allowable to take advantage of the tolerance to the detriment of the coinage, therefore each bag of 1,000 sovereigns is generally made up of heavy and light pieces within the remedy, in order to bring it to the exact legal weight, *viz.*, 256.82 oz. troy.

In 1851 this machine, modified by Richard Pilcher, so that heavy as well as light pieces within the remedy could be separated from those unfit for issue, was introduced into the London Mint, and modifications of it are used in nearly all mints.

The balance is contained in a skeleton frame of brass with glass sides. It is about 20 inches long by 8 inches wide and 10 inches high. The beam is of peculiar shape, having its centres of gravity and action in one line. The pan for receiving the coin or blank is suspended on the knife edges at one end of the beam, and it has a pendant rod with a loop at its lower end; a second pendant, also having a loop at its lower end, is poised upon the other knives carrying the minimum weight of the coin, and, in a cage, the double remedy weight, which, unless raised by the weight of a too heavy coin on the opposite end of the beam, lies in V's formed on a little adjustable platform attached to the floor of the machine. The pieces to be weighed are placed in a hopper on the top of the machine, and the lowest one is pushed on the pan by a slide working underneath. A centrally pivoted levelling bar passes through the loops of the two pendants to bring the beam to a horizontal position before and after each weighing. A pair of forceps holds the pendant under the pan and thus keeps the beam rigid while a piece is placed on the pan or pushed off it. If the piece is too heavy it will lift both the minimum weight and the double remedy; if too light it will not move the

minimum weight; if correct, the beam has a well defined range of action between the two extremes. Assuming the machine to be in motion, the forceps again grip the pendant, and a weighted and nearly counterbalanced vertical rod is released; this rod is pinned to a pivotted lever, the opposite end of which passes through the upper part of the loop in the front pendant and projects beyond it. The delivery end of the shoot is meanwhile moving above three openings leading to boxes into which the heavy, good and light pieces fall. The end of the pivotted lever whose downward motion is arrested by a knife-edge across the loop, then touches the shoulder of a second lever beneath it, which is pivotted on the same pin as itself. This lever has a weighted extension inwards, and when it is depressed by the touch of the first lever it comes in line with one or the other of three inverted steps formed on a fitting attached to the shoot, and, entering, it places the shoot in position to deliver the piece into the proper box. The beam is then released and brought to a horizontal position, the forceps hold the pendant, and the weighed piece is pushed off by another coin. All these movements are carried out by cams on the three shafts of the machine, motion being conveyed from the driving shaft by accurately cut gears.

The drive is by power which is certain to be uniform, such as an air-engine or small water-turbine, and the connection with each machine is made by frictional contact between the boss of the driving wheel and a milled disc, so that if any excessive pressure should occur, such as the locking together of two wire-edged pieces, the machine would stop. The balances are constructed to weigh eighteen pieces per minute, correct within 0.01 grain.

During the past forty years the machine has been much simplified in the workshops of the Royal Mint, London, and the latest types, while retaining the essentials of the balance described above, have but one shaft, upon which all the cams are mounted.

Up to the present time no important improvements in rolling machinery have been effected, beyond the adoption of the electric drive. The invention of carborundum wheels has, however, provided a means of dressing rollers with the greatest accuracy.

The modern cutting press is self-contained and usually belt driven. The frame carries a crank-shaft with fly-wheel and pulleys, and on the crank-pin a short and heavy connecting rod is fitted. The rod actuates a massive slide moving in vertical guides. In some machines this connecting rod is omitted, and an overhung crank pin is fitted into a brass in a steel sliding-block working in a slotted opening formed in the slide. The

under-side of the slide is machined with a dove-tailed joint, so that the punch bed, slotted to fit the joint and with its two or more punches inserted can be slipped on and fixed by a plate and bolt. A pair of geared rollers receives the end of the fillet and passes it under the punches, after which a second pair takes the skeleton of the fillet and guides it away. These rollers obtain their motion from cut wheels on two spindles geared with a driving shaft, on the outside end of which a ratchet wheel is fitted. A slotted disc revolves on the free end of the crank-shaft and one end of a connecting-rod is bolted in the slot in such a position that its opposite end, which carries a spring pawl on a short lever, can advance the ratchet wheel by a definite number of teeth corresponding to the space required between blanks of any denomination. The bolsters are fixed on the bed of the machine immediately beneath the punches, and have a steel plate above, perforated so that the punches can easily pass through; this arrangement ensures the release of the punches on their travel upwards.

A machine is used in many mints for compressing or "marking" the edges of blanks in order that the "beading" around the circumference of the coins may be well impressed without imposing unnecessary strain upon the dies.

The essentials of such a machine are a disc mounted on a driving shaft, the disc being provided with a ring of hardened steel having a groove recessed in it, a block of hardened steel with a groove concentric with the disc, a stepped wheel for spacing the blanks, and a feeding tube.

In action, the revolution of the step-wheel removes the blanks one by one from the feed tube and passes them down an incline leading to the grooves in the revolving disc and the fixed segment, in which they are revolved two or three times before being ejected. A slight deepening of the groove in the segment enables each blank to enter far enough for the impetus of the revolving disc to grip it and carry it through the race. This machine can be used for all ordinary sizes of blanks, adjustment of the segment being all that is necessary.

Another type of machine has a horizontal disc with the groove in its rim; in this case a horizontal wheel with leaves of the same thickness as the blanks and spacing identical with their diameter, revolves under the feed-tube and throws blank after blank into the race. Two feed-tubes are fitted to this machine and an output of 1,200 pieces per minute can be maintained.

There are two types of coining press in use to-day, the French and the German, or Unlhorn.

The French press is housed in a single massive casting, the front taking the pressure of coining, the back carrying a

crank-shaft, with a heavy fly-wheel and pulleys. A short vertical steel casting connects the crank shaft with a strong cast steel rocking-lever, the front and larger end of which is machined and suspended by a link on each side to two rectangular rods passing through the upper part of the press, where they are turned, threaded and fitted with nuts bearing upon the top. A rectangular opening slotted through the lever has a toggle driven through and secured. The upper and hollowed end of the toggle receives and supports the projecting end of a knuckle placed in a slot machined in the casting immediately above it. A wedge over the knuckle operated by a screw and hand wheel enables it to be raised or lowered in conjunction with similar movements of the suspension rods of the rocking lever, thus affording the means of increasing or reducing pressure between the dies. The lower and rounded end of the rocking lever toggle fits into a hollow joint in a rocking-column, which has its lower knuckle fitting into a joint in a block guided in projections formed at the sides of the front opening of the press. This block is hung upon links connecting it with the rocking lever. The under-side of the block is recessed out to receive the upper die-block held in position by set-screws. At the free end of the crank-shaft a disc is fitted on which an adjustable rod is pinned eccentrically; over the disc a wooden brake-block is housed. The eccentric rod is connected with an oscillating crank whose rod is carried in bearings across the press and has midway an arm and links connected with two squared parallel rods moving to and fro in guides. These rods are connected by a bridge-piece in front of the press.

The bed plate is constructed in two pieces and is fixed over the sliding frame and secured by bolts and nuts to sills projecting on each side of the opening, dovetailed slots being formed in order to receive the heads of the bolts. This plate receives the collar, and each portion of it has a semi-circular opening with a recess turned in it, so that the collar with its projecting ring fits into the bed-plate flush with its upper face. The bed-plate has the feed-tube mounted upon it and two L-shaped grippers for placing blanks on the lower die and removing the coins. The ends of the short arms of the grippers are pivotted on pins in bosses formed on the right and left hand of the bridge connecting the two sliding rods, the front of the bed-plate being cut away so that the bosses do not come in contact with it. The opening and closing of the grippers is regulated by a slider moving in a guide formed by cutting a longitudinal slot through the front portion of the bed. Two lugs on the slider engage in recesses in the adjacent slides of the long arms of the grippers, and on the under side of the slider a circular brassed recess takes an oval pin in a boss projecting from the centre of the bridge-piece.

The amount of free movement permitted to the slider by the oval pin is sufficient to enable the grippers to open and close when the sliding frame reaches the end of its travel backwards and forwards.

At the lowest part of the front of the press an adjustable wedge is fitted and upon this a massive equilateral T-shaped block is placed. Its upper part is recessed to take the lower die, which rests upon a second smaller adjustable wedge; the under side of this portion of the block carries two hardened steel projecting segments. The die block is accurately squared, its top fitting into a recess formed over the sliding frame, which is here provided with two hardened steel strips rivetted to the two squared rods. These strips are humped so that the die-block is lifted at the right moment from its position on the large wedge in order to bring the lower die flush with the collar when a coin has to be pushed off. The lower part of the die-block also fits into a machined opening, the front of which is closed by bolting on a guide plate. The die-block is therefore capable of vertical motion only.

The fly-wheel and fast pulley run free on the shaft, and the raising of a small lever in front of the press engages them with the shaft by means of a sliding pin. Attached to the starting lever is a valuable device by means of which the press automatically stops should there be no blank between the grippers. A light rod having a pin at one end lies between the grippers and is connected with a spring trigger engaging a collar on the vertical rod attached to the starting lever. The closing of the grippers without a blank causes the rod to trip the trigger and disconnect the mechanism before the dies can come together and be damaged.

The Uhlhorn press has a heavy front casting, with feet, and a framed back carrying the crank-shaft, with two cams and fly-wheel with pulleys. Back and front are connected by a C.I. bed about 2 ft. 6 in. from the ground, and the necessary tie rods. The crank has a turned rod connecting it with a bell-crank. The knuckle in the top of the front opening is fixed, and the bell-crank with its two knuckles is suspended on the points of set-screws passing through its sides and terminating in coned recesses in the top knuckle. A rocking column operated by the projecting toggle in the bell-crank has a knuckle fitting into a hollow joint beneath it, which is bedded into a strong flat hammer-lever pivotted upon a bolt which passes through the cheeks of a bracket on the bed of the machine. In a recess formed through the rocking column immediately over the lower knuckle and bearing on it a wedge is placed, which is moved by a nut and screw, and enables the pressure on the dies to be regulated. The lower parts of

the back and front of the rocking column are capable of up and down motion, corresponding with the movements of the wedge. The upper die is attached to an adjustable block fixed in a ring on the under-side of the hammer-lever.

Heavy weights in a cage under the bed of the press are balanced on a lever carrying two vertical rods beyond its centre of action. These rods pass through holes in the bed, one on each side of the hammer-lever, at the level of the under-side of which they are bridged across, forming a support for it and the rocking column and keeping the toggles in contact. Immediately under the hammer-lever is a second flat lever, familiarly known as the "banjo," from its shape. The far end of this is slotted so that it will slip on a pin passing through the same bracket as the hammer-lever. The "banjo" has a circular opening through it immediately under the upper die—the collar is fixed in this opening. The bottom die is fixed on a block, the lower part of which is slightly rounded so that adjustments can be made by means of the four set-screws which secure it inside a heavy ring screwed down to the bottom of the front opening. The neck of the die enters the collar.

The end of the "banjo" projects about a foot beyond the circular part and carries the feeding-tube, and, in a guide, one end of a layer-on rod, to which the fittings are attached for placing a blank on the die and removing it after coining. The opposite end of the rod is connected with a vertical lever pivotted to the inside of the back frame, having a backward set at its short upper end in order to carry a roller in a forked holder with a hardened end pin. The pin presses the roller against a cam by means of a strong flat spring attached to the back of the frame, the cam's revolution maintaining a to and fro motion of the layer-on. The lever has a pivotted arm kept in position by a coiled spring with ratchet and pawl, giving a measure of elasticity to it and at the same time exerting a back pressure on the layer-on rod. If jambing of the pieces should occur in the feeding-tube, the spring-held portion of the lever would be pulled away and serious damage to the dies averted.

One end of a vertical rod is attached to the under-side of the "banjo" in front of the press and connected below with an end of the heavy fish-shaped lever, which at its opposite end is pivotted to a vertical rod having a forked upper end, in which the second cam revolves. Above the cam is a short lever pinned through the top of the fork at one end and at the other through the end of a curved bracket-rod projecting from the inside of the back frame. This lever carries a roller in an adjustable forked holder immediately over its cam, kept in contact by the weight of the fish lever. This arrangement provides for the necessary up an down motion of the collar.

The fly-wheel of the press runs freely on the shaft and when

the tube is filled with blanks the press is set in motion by moving a pivotted lever, to which a clutch is attached.

In conclusion, I believe I have referred to all the principal minting machines in use at the present time, although there are many subsidiary appliances now employed in some mints which enable coinage operations to be conducted more expeditiously and with less cost than was the case when engineering had not attained the high standard it has reached to-day.

(11th September, 1918.)

ELECTRIC POWER ON THE KALGOORLIE MINING FIELD.

By C. E. Crocker.

When the mines of the Golden Mile were opened up, the extent to which the treatment plants would ultimately develop could not be foreseen, and in the early stages no effort was made to establish a central electric power station. Later developments proved that the field was especially suited for such a combined plant, as the greater part—in fact the whole—of the principal mines are concentrated in a comparatively small area, known as " The Golden Mile." Undoubtedly, had the mining companies in the early days joined in the establishment of a central station for the supply of electricity and compressed air for all purposes, or had a company taken up such a supply, a great economy of expenditure on plant and operating cost would have been effected.

Such a plant could have been located approximately centrally to the mines, and the distribution of current and compressed air would have been simple, and the deletion of the individual power plants would have materially reduced the space occupied on the surface of each mine.

A combined plant would have required to have a capacity suitable for a load of about 20,000 to 25,000 kilowatts, and would have operated most favourably, considering local conditions, and would have been a highly interesting plant from an engineering aspect.

There was not, however, up to about 1898, any concerted action for a central plant. Therefore each of the mines proceeded with the construction of their own steam plants as required, and these were gradually enlarged, the use of electricity being up to then confined to isolated lighting plants on individual mines.

About 1898 the Kalgoorlie Electric Power and Lighting Corporation, Limited, which I shall call " the power company," as it is generally known, was organised.

Owing to delays in organisation, the plant was not ready for operation until 1902, by which time the mines were well equipped with steam plants, and the introduction of electric power from the central station was consequently slow and difficult, and has never superseded steam for hoisting or air compressing on the large mines. Notwithstanding the late starting of the central supply, and the poor outlook at first, the supply of power taken from it by the mines increased at

times to an extent that made it difficult to keep up the supply while additional generating plant was being installed.

As treatment processes were altered on the mines, requiring the re-organisation of the treatment plants, electric drive was generally adopted, and in most cases the Power Company was successful in supplying the power. In several such cases individual loads of 400 to 700 kilowatts were added. The necessity to take up such extra loads, before additional machinery could be installed, taxed the capacity of the plant severely at times.

Conditions.

The conditions of power generating on the Goldfields were and are somewhat unusual and difficult. As you gentlemen are mostly well aware, the climate is pretty hot and very dusty, and before the roads and streets were as well made as at present the dust was very much worse than now. I have frequently seen the temperature in the engine room of the power plant from 120° to 125° Fahr. during the greater part of the day, and this would usually be brought to a climax by a wind storm, during which the dust penetrates everywhere and thickly settles over the machinery. But the storm, fortunately, usually brings a cool change, and relieves the tension on both man and machinery.

Besides the heat and dust, which add considerably to the rate of depreciation and make extra attention to maintenance and repairs very necessary, the condition of fuel and water supplies were and are unusual. There is no coal available nearer than Collie, which would necessitate a rail shipment of approximately 434 miles.

The transmission of power from Collie has frequently been suggested, but the distance is too great for it to be practical commercially, especially in view of the uncertain life of the mines, which has always been a controlling condition on the Goldfields. As reliability was the great essential of a central supply, a double pole and transmission line would have been necessary, and calculations showed the capital charges on the lines alone would amount to practically the cost of generating the power on the Goldfields.

On the other hand, the natural timber is specially suitable for fuel, and has always been cheaper than coal, in spite of the extra cost of handling wood. The forest has been cut out until most of the wood is now brought from a distance of between 75 and 100 miles. The wood is principally salmon gum and mulga, and is used in 5 ft. lengths in boilers. The calorific value is between 4,000 and 5,000 B.T.U. per lb., being just about one half that of Collie coal and somewhat more than one-third that of Newcastle coal. The present cost of

the wood is between 13/- and 14/- per ton on trucks at the mines.

No mechanical means have been devised for handling or stoking this fuel, and consequently each piece, whether large or small, is handled separately throughout its travels from the bush to the boiler furnace. The contracts for the wood supply generally limit the largest diameter of any piece to 10 in., and provide that logs larger than that shall be split. Even logs of that size 5 ft. long are very heavy, and are handled in stoking by tipping one end at a time.

The water supply has always been a serious problem, and is a heavy expenditure in power production on the fields. Before the advent of the supply from Mundaring, beyond the little which could be conserved in dams from the very uncertain rainfall, the boiler water had to be condensed from the subterranean salt water. The evaporation and condensation of this water was an expensive operation, as the underground water (which was usually taken from the mine shafts at a depth of 300 to 400 feet, and where the flow was not over 25,000 gallons per day at any one shaft) was very heavily impregnated with salts, the total solids frequently running as high as 20 per cent. In consequence of this, the tanks or boilers in which the water was evaporated had a very short life, and required a great deal of cleaning. Condensation was effected in the familiar corrugated galvanized iron cylinders.

The price of dam and condensed water for boiler use varied between 35/- and 60/- per thousand gallons, and the actual cost of condensing ran from 30/- to 40/-, including pumping.

The price of water from the Mundaring supply is 7/- per thousand gallons for boiler water, and while this is a great reduction from former conditions, the price is still very high compared to that at most places where large power is generated.

In consequence of the high cost of fuel and water, it has always been necessary to use steam engines of the most economical type possible. That fact has prevented the use of steam turbines extensively, as they have not been built (at least until very recent years, if at all) in the sized units required in the plants as they exist on the fields, with anything like as low steam consumption as the higher class engines would give. I will refer later to the comparative steam consumptions of the various types of engines in use, when describing the plant of the Power Company.

Owing to the high cost of fuel and water, the Goldfields would appear to offer a most suitable opening for suction gas plants. But, while such plants have been used to some extent on the Kalgoorlie field in small units successfully, and on the outlying mines, where central electric power was not available, their

comparative unreliability has prevented their use on the large mines, where an unintentional stoppage of even a short period means a heavy financial loss. Gas engines would have been utilised by the Power Company except for that reason.

VARIOUS PLANTS ON THE MINES.

For the past ten years, the greater part of the electric current used by the mines, with one or two exceptions, has been drawn from the service of the Power Company.

The Golden Horseshoe and Ivanhoe mines have generated their own electric current, and the Lake View and Star mine generate a portion of their requirements.

Of these isolated plants, that of the Golden Horseshoe is the most important. It consists of two high pressure steam turbines, each of 625 K.V.A. capacity, and one low pressure steam turbine of 938 K.V.A. capacity, all built by the A. E. G. Company.

The high pressure units work on 150 lbs. steam pressure, super-heated to 550° to 600° Fahr., and each exhausts direct into its own condenser. The low pressure unit operates on the exhaust steam from the mill engine and the 70-drill air compressor, and also exhausts into its own condenser.

All condensers are of the surface type, and are installed underneath the turbines.

The cooling water is circulated by motor and turbine driven pumps through cooling towers, where the water has a drop of 40 feet.

In the towers the temperature of the water is reduced about 20° Fahr. average through the year, the circulation being equal to 45 to 50 lbs. per lb. of steam condensed, and the average vacuum obtained is 26½ in., with the barometer reading at 28.7″ average in Kalgoorlie.

The cooling towers are arranged in two different ways at the Horseshoe Mine. In one tower there are a number of floors for breaking up the water as it falls through the tower, and above these floors are arranged a set of sprays through which the water is projected. In another tower the water is distributed at the top through launders or distributors and flows through a series of floors or barriers made up of brush. The water running over the various twigs and branches of the brush is well exposed to the air, and the cooling in this tower is said to be considerably more effective than that in the tower formed of sprays and floors.

The steam consumption tests of the high pressure sets vary between 21 and 24 lbs. per kilowatt, and the low pressure set takes about 37 lbs. per kilowatt hour on test at the mine.

The compressor which exhausts to the low pressure turbo is the largest in the Southern Hemisphere. The steam cylinders are 27″ H.P. and 50″ L.P. diameter, and the air cylinders $28\frac{1}{2}$″ H.P. and $46\frac{1}{4}$″ L.P., with a 5 ft. stroke. The capacity is 7,000 cubic feet of air per minute.

The plant at the Golden Horseshoe mine has many interesting features, and has been very successful.

The turbine generators supply three-phase alternating current at 560 volts, 50 cycles. The voltage is closely controlled by Tirrel voltage regulators. It is noteworthy that the stators of the high pressure turbine generators are cooled by a water jacket as well as air ventilation. The low pressure set is air cooled only.

The output of this plant, when the treatment was in full working, has exceeded the rate of 7,000,000 units per year.

General Supply.

The general supply to the mines is furnished by the system of the Power Company at a normal voltage of 550 volts at the consumer's premises, 3-phase, 40 cycle. The original plant, which was first operated in 1902, consisted of Babcock and Wilcox boilers, vertical cross compound Stewart Carliss engines, and Fouche aero condensers.

All the boilers and machinery are housed in structural steel buildings covered with corrugated galvanized iron, with concrete floors. The arrangement of the plant is the customary one, with the boiler house parallel to the engine house, and the railway siding delivers the wood fuel directly in front of the boilers.

Since the plant was originally installed, four additional generating units, together with necessary boiler equipment, have been added. These units consist of three horizontal cross compound drop valve engines, and one mixed pressure Parsons turbine unit. The condensing arrangements have also been altered, owing to the arrival of the water supply at Kalgoorlie, and barometric and jet condensers are now in use. The generating plant at present has a total of 4,600 K.V.A. rated capacity. Of this, however, two of the original 500 K.V.A. units are practically never used, and serve only as stand-by in case of extreme urgency. Hence with 3,600 K.V.A. in active use, 2,600 is run practically the full 24 hours, except Sundays.

With this equipment the output has exceeded 15,000,000 units per annum, which is exceedingly high for a plant of such a rated capacity, and is due to the very high load factor, of 70 per cent. or over, under which the plant operated. This high load factor was due to 95 per cent. of the output being

used by the mines for treatment plant where the load is very steady, and which, until recently, ran practically seven days a week full time. Since the war started, owing to various factors, the mines are now shutting down on Sundays, so that the load factor is not as good as it was before.

The steam is generated in Babcock and Wilcox land type boilers at 160 lbs. gauge pressure, and superheated to 460° to 500° Fahr. at the engines. The boilers are hand fired with wood fuel, which as far as possible is thrown direct from the railway trucks to the front of the boiler, ready for stoking. Of course, it is necessary to keep a large quantity of wood as reserve, and generally the amount of wood stacked on the lease is between 4,000 and 5,000 tons, or practically one month's supply at full load. This wood requires a considerable space for storage. The stacks are not used up until shortage of supply compels it, as the deterioration in calorific value after the first few months is negligible.

A CO_2 recorder is constantly in use on the flues, and has been found of much assistance in detecting leaks in boiler settings and also in encouraging the boiler attendants to obtain better firing results. A satisfactory system of stoking with wood is difficult to obtain. The universal system adopted by the firemen is to fill the furnace full and leave it until well burnt down, and then refill, instead of lighter and more frequent stoking. As the fire doors have to be fully open while stoking, the system is obviously not efficient. The evaporation obtained in the Babcock boilers, as determined by numerous tests, averages $3\frac{1}{4}$ lbs. of water from and at 212° Fahr. per lb. of wood.

All the water used by the boilers is filtered through a sand bed in a Patterson water treatment plant, and is measured by a Lea recorder. The water received from the main contains a good deal of suspended matter in the form of fine red dirt and oxide from the interior of the water scheme pipes, and at times it is quite red, hence particular attention has been devoted to the filtering arrangements.

The original vertical Corliss engines were very heavy, strong machines, and capable of hard duty. These units were at one time, owing to shortage of capacity, run at 25 per cent. over load almost constantly for several months, until a new unit was installed. These engines were, however, "steam eaters," and were mistakenly selected for Goldfields use. The steam consumption averaged 27 to 28 lbs. per kilowatt hour on the regular commercial load with a 23″ vacuum. Some years ago arrangements were made to convert one of these to a Sulzer valve gear (*i.e.*, drop valve), and the work was very successfully executed by a Melbourne foundry. The arrangement was rather difficult to attach to an existing engine without altering the trunks of the engine, and the valve

chambers had to be set outside of the cylinders, which makes the working somewhat noisy. The steam consumption, however, was brought down to 22 lbs. per kilowatt hour by the change, and a much more satisfactory engine, as regards upkeep and reliability and suitability for superheated steam, resulted. The cut off gear on the high pressure inlet valves is effected by a moveable rod controlled by a trip actuated by the governor. The valve gear on each cylinder is driven by a vertical shaft carried on ball bearings operated from the bevel gear on the main shaft of the engine. The vertical shaft drives through another set of bevel gears the short lay shaft on the cylinder, which carries the eccentrics and cams which actuate the valves. No troubles whatever have been experienced with these valves after a number of years' operation. The difference in the original Corliss valve and the altered engine is interesting both from the point of view of steam economy and upkeep cost and reliability of operation. In the original Corliss engines considerable troubles were always experienced with the large valves, these troubles being principally due to lubrication difficulties, and the seizing of the valves and the twisting of the spindle through which they were driven. They were also unsuitable for use with superheated steam.

It is interesting to note that the poppet valve, which made the engines of Sulzer Bros., Switzerland, famous, was first applied by them about 50 years ago, and was designed by an English engineer, Chas. Brown, at that time chief engineer of Sulzer Bros. The poppet valve engine was taken up generally on the Continent, but English and American engine designers and builders adhered to the Corliss valve until comparatively recent years, and were apparently only forced to admit the virtues of the poppet valve by the extended use of superheated steam. Some English firms adopted it several years before American designers, but it is only in the last eight or ten years it has been seriously taken up, although it has long been the standard on the Continent.

The poppet valve has several advantages over the Corliss, amongst which are:—

Less weight, being one-tenth to one-fifteenth as heavy as a Corliss valve having the same steam area.

No rubbing surface to introduce wear and lubrication troubles.

Suitability for high temperature and high pressure.

Long life, due to the little wear and much improved steam economy.

In the Kalgoorlie engine all the difficulties of the Corliss gear were overcome by the new arrangement. The alteration was so successful that it was quite intended to alter the remain-

ing two vertical engines in the same manner, but, owing to the necessity for increasing the capacity of the plant, additional units were installed, and the Corliss engines were retained merely as emergency stand-bys without alteration. As you will appreciate, with a load where continuity is so important, as is the case with gold mining, it is necessary to have not only the usual provision for stand-by plant, but something in addition to that as a reserve in case of extensive breakdowns.

These original sets were fitted with 600-volt generators of the revolving field type, built by the General Electric Company of America.

In 1904 a 23½" x 38" x 41½" horizontal engine, having a capacity of 930 I.H.P., built by Frank O. Tosi, of Legano, Italy, was installed. This machine is fitted with poppet valves of the double port balanced type, and has proven very reliable and satisfactory in operation. The steam consumption of this engine on commercial load taken over an eight-hour test is 18½ lbs. of water fed into the boilers per kilowatt hour, including the losses in the steam jacketing of the cylinders. This unit is fitted with a Westinghouse 500 K.V.A. 600-volt generator, and exhausts into the main exhaust pipe to the barometric condensors.

In 1909 another horizontal unitl, consisting of 30" x 54" x 48" stroke engine, rated at 1,600 I.H.P., and built by Cole, Marchant and Morley, of Bradford, England, driving a 1,100 K.V.A. A. E. G. 3,300-volt generator, was installed. This engine is fitted with the Morley patent piston drop valve, which in external appearance is somewhat similar to the Tosi engine, but the valve itself is of quite a different type, and consists of a very light casting of special quality iron carrying piston rings, and its particular virtue is its great lightness, so that all of the valve gear is correspondingly reduced in weight, and the working of the valves themselves, as they do not fall on a seat, is more quiet than that of the type of valve gear used in the Tosi engine. Experience has shown, however, that these valve gears are more sensitive, and, as a consequence, are liable to cause more trouble than is the case with the Tosi gear. The steam consumption of the engine on commercial test is the same as that of the Tosi—18½ lbs. per kilowatt hour, although it is double the capacity of the Tosi engine.

This engine also exhausts to the main barometric condensers.

In 1912 a horizontal 25¼" x 43¼" x 35½" engine, built by Carel Freres, of Ghent, Belgium, rated at 825 I.H.P., driving direct a 550 K.V.A. A. E. G. outside revolving field type generator, was installed. This engine has several novel features, and is a very fine piece of work mechanically. The engine is

fitted with valves of the Lentz type. These valves are of the double seated drop valve type, similar to those in the Tosi engine, but instead of being mounted in the body of the cylinder, both steam and exhaust valves are mounted in the heads of the cylinder, thus reducing the clearance space in the cylinder. The body of the cylinder is consequently merely a barrel in which the piston works. This construction is mechanically strong.

These valves, in falling before they finally close on the seats, enter a contracted portion of the valve casing, where the steam is practically cut off and a cushion is formed, which, in addition to the outside dash pot, considerably reduces the shock of the valve on the seat, making them very quiet in working. These valves have proven exceedingly reliable, and the maker's faith in them is indicated by the fact that they give a 20 years' guarantee of the valve. This engine is the most economical in the station, and the steam consumption is, on commercial test, 16½ lbs. per kilowatt hour, which is very low for a 500 kilowatt set.

It must be borne in mind that all consumptions mentioned are taken under actual working conditions on commercial load in Kalgoorlie, and represent the water evaporated by the boilers when the engines are working on a 23″ vacuum.

The Carel unit exhausts into a horizontal jet condenser located under the engine, the combined air and water pump for which is driven by a rod from the low pressure crank pin of the engine. When the plant was installed there was some fear that this drive arrangement would not prove reliable and might cause trouble and interruptions; such has not been the case, however. Another special feature of this unit is the type of generator. In all of the other slow speed sets the revolving field is inside of the armature or stator. In this unit, however, the armature forms the inside portion and the revolving field is outside, the object of this arrangement being to increase the fly-wheel effect with economy in material.

In 1913 a Parsons mixed pressure steam turbine unit, having a capacity of 750 kilowatts, at a 75 per cent. power factor, was installed. The generator is direct wound for 3,300 volts, and the steam turbine is capable of carrying its full load on the high pressure side only. For some time after the unit was installed it was operated on mixed pressure, the low pressure steam being taken from the exhaust of the engines. It was found, however, that the plant economy, after the use of the Corliss engines was discontinued, was not increased by this arrangement, as the extra steam taken by the drop valve engines when exhausting to the turbine against the back pressure was, with the exception of the altered vertical engine, about 40 per cent. greater than when running condensing, and that this

decrease in economy was not compensated for by the working of the turbine as a mixed pressure set. Recently the turbine has been used practically as a high pressure unit. Under these conditions, the steam consumption is 22½ lbs. per kilowatt hour on commercial load, when working with a vacuum of 25″.

Previous to the installation of this unit, turbines were not installed in the Power Company's plant, as mentioned before, because the type of engine used gave a great deal higher economy under Goldfields conditions, where a high vacuum cannot be obtained without heavy expense in pumping circulating water.

At the time the Tosi engine was installed, calculations based on the manufacturer's guarantees, later confirmed by actual tests, showed that the extra economy with the engine would pay for the difference in cost between the engine and a turbine set of the same capacity in one year's operation, although the slow speed engine cost installed twice the amount that a turbine set of the same capacity would cost. This fact would not, of course, hold good for units of over 2,000 kilowatt capacity, in which size the turbo economy is better, but, owing to the way in which the power plant was built up and the uncertainty of the life of the mines, it was necessary to use generating sets of smaller capacity.

In spite of the filtering arrangements in use for the feed water. considerable trouble has been experienced in the Parsons turbin owing to the accumulations of dirt and oil on the blades. To all appearances the filtered water is quite clear, and one would expect that the velocity of the steam passing through the turbine would carry with it into the exhaust any such solids as may come over with the steam. But this deposit forms on the blades, gradually reducing the capacity of the turbine, until it is necessary to open it up and carefully scrape and blow out the blades every six to twelve months. The deposits will accumulate if allowed to do so until there is practically no space left between the blades for the passage of the steam. It is so fine and soft that no trouble has been experienced through the deposit getting between the moving and stationary blades. The spraying of kerosene into the steam inlet has helped to decrease the accumulation, but does not prevent it altogether. The difficulty seems to be peculiar to reaction type turbines, as I have not heard of it occurring with impulse type turbines in use in Kalgoorlie.

The turbine set exhausts direct to one of the barometric condensers, which is also connected to the common exhaust pipe.

Condensing Arrangements.

The original Fouche aero condensers, which were installed before the water supply was available, were interesting, and gave very good service. These condensers consisted of a large

number of narrow chambers constructed of thin corrugated steel plates, spaced about $\frac{1}{4}''$ apart. Each of the steel chambers has 1,345 sq. in. of cooling surface, and 51 chambers are grouped together in a bundle, and 15 bundles are mounted in a compartment or section of the condenser. This gave an area of 7,141 sq. ft. per section, or 21,423 sq. ft. of cooling surface per unit, condensing 13,500 lbs. of steam per hour, approximately equal to 1.59 sq. ft. per lb. of steam condensed per hour.

Each section is enclosed in a steel casing with open top, and supplied with air by three fans 7 ft. in diameter, running at 320 r.p.m. Three of these sections were used to condense the steam from a 500 kilowatt unit ,and required 45 H.P. for driving the fans, which is equal to about 8 per cent. of the output of the generating unit for which the condenser acts. With these aero condensers the vacuum necessarily varied with the temperature of the atmosphere. The average obtained was 18″ throughout the year, ranging from zero, when the temperature of the external air was above 113° Fahr. (shade temperature) up to 22″ vacuum with a temperature of 43° Fahr. (shade temperature). The condenser was very economical as regards loss of water, and only 5 per cent. of make up water was required to supply the boilers, as against 25 per cent. to 30 per cent. with barometric condensers and cooling towers. Careful calculations, checked by test, showed that the condensers could be operated more cheaply than either surface or jet condensers when the price of water exceeded 5/- per thousand gallons. Owing, however, to the excessive capital expenditure and the space occupied by these condensers, the use of the plant became inadvisable, and barometric condensers were installed.

A set of Fouche condensers suitable for 500 kilowatts cost approximately £16,000, as against some £2,500 for a barometric condenser unit, including pumps capable of doing twice the work.

The writer would have no hesitation, after the experience of their working in Kalgoorlie, in adopting these condensers in locations where the price of water is very high, and the capital cost is permissible for any plant of small capacity. The climate of the fields is very dry, and no trouble from corrosion of the steel chambers occurred during the four or five years the condensers were in use. If used at intervals only, so they were standing cold a large part of the time, or in a moist climate, they should be protected by a roof.

The condensers now in use consist, in addition to that on the Carel engine, of two large barometric condensers, one mounted at each end of the main engine room and connected by a 24″ main exhaust pipe, into which all of the engines, except the Carel unit, exhaust. Barometric condensers were

chosen instead of surface condensers owing to their great reliability and the less quantity of circulating water required to obtain the same vacuum. These condensers have proven very satisfactory and require practically no attention, except that the water attacks the inside of the steel shells and trays, necessitating periodical scraping and painting. This being attended to about once a year, the corrosion has been reduced to a reasonable item.

The circulating water is pumped to the towers by both motor driven and steam driven centrifugal pumps, stand-bys being provided at each condenser. One set of pumps is driven by an Allen steam turbine rated at 120 H.P., which has proved very reliable in operation. It consumes 30 to 35 lbs. of steam per horse-power. Mirlees Watson slide valve vertical vacuum pumps are used, being driven by electric motors.

Trouble is experienced with the corrosion of all steel pipes around the plants in Kalgoorlie when using Mundaring water supply, probably owing to the excess air contained in the water. So much trouble was experienced with this difficulty at the power plant that wooden pipes have been gradually substituted for circulating pipes leading from the pumps to the cooling towers, and these have given every satisfaction. They are also in use for the water main into the plant, and for the blow-off pipe of the boilers.

Although corrosion trouble is not experienced in the boilers, this action of the water was very serious in the feed pipes, which deteriorated so rapidly that it was necessary to renew the heavy hydraulic pipe every twelve months. This became such a heavy item of expenditure that after investigation it was decided to instal lead-lined steel pipes throughout the feed system. These pipes have practically overcome the difficulty, and have been in use now for some six or seven years without any trouble occurring.

Three separate cooling towers are in use at the power plant, part of which are arranged with the launders and floor system, and the others with sprays and floors. The water falls a total distance of 23 feet in these towers. In summer the inlet temperature rises as high as 90° in the hottest weather, being reduced from about 125°, at which it leaves the tail pits of the condensers. The towers are all of the natural draught type, the structure extending 40 ft. to 50 ft. above the water.

As the output of the plant increased it was found desirable to raise the transmission voltage, and 3,300 volts was adopted. Transformers were installed in connection with the original 600 volt generating units, and the later generators were wound direct for 3,300 volts.

The current is transmitted to the mines by overhead lines on wooden poles, and very heavy copper lines are used, owing to a considerable portion being transmitted at the lower voltage. Both the 600 volt and the 3,300 volt wires are carried on the same poles. The mines furthest from the power plant are supplied through transformers at the sub-stations, where the voltage is reduced to 550 volts for the motors. Three of these sub-stations are in use, two having a capacity of 675 kilowatts each and one of 900 kilowatts. Single phase transformers are used and connected delta on both primary and secondary, so that in case of breakdown of one transformer, the service can be partially maintained on the remaining two transformers. The sub-stations are, as is the case with most buildings on the mining field, where the future is very uncertain, constructed of wood framing and covered with galvanized iron. All transformer circuits and the feeders at the power station are provided with automatic oil switches on the high tension side. Both electrolytic and multi-gap lightning arrestors are used on the main feeders.

All the outlying district is supplied through overhead lines and pole type transformers. The Goldfields are subjected to very heavy lightning storms at times, which are especially fierce after a long dry spell. Considerable trouble was originally experienced from these lightning storms through burning out of meters and motors, and to overcome the difficulty a large number of additional lightning arrestors were placed in service, effecting a very decided improvement. Lightning arrestors are now used at the ends of all lines both on the 3,000 and 550 volt circuits, and at all branch lines and transformers.

Current is supplied for the Kalgoorlie electric tramway system through three 200 kilowatt converters, installed in the power station. The load of the tramways is very fluctuating, as the number of trams in use on the average is only eight or nine, with an average daily requirement of about 200 H.P., while on holidays and race days the peak load on the tramways often runs up to over 1,000 H.P.

Mine Motors.

Electric power has never been adopted on the mines for large winding engines or compressors, principally because the large steam plants were installed before electric power was available, and the capital cost of electric winding installations is very heavy, and there would have been little or no gain in economy.

A great variety of motor applications have been made to the general mining machinery.

A number of the drives at the Golden Horseshoe mine are well arranged. Fifty horse-power individual

motors are used for driving portion of the tube mills through spur gear. These tube mills are formed with a long cylindrical steel casing mounted on an incline, and the crushing inside of the mill is effected by flint boulders, the unground ore being fed in at one end of the cylinder, and passing out after grinding at the other end. In other cases several of the mills are driven from a counter-shaft by larger motors. A 160 H.P. motor drives through a rope drive, four of the tube mills, and 14 concentrating tables. The motor is carrying an average load, with all machinery working, of 180 H.P., which it appears to do without burning out.

Until within the last few years most of the tailings on the mines were deposited in dumps on the leases. On the Golden Horsheshoe the tailings were conveyed to this dump by means of a long belt conveyor, which required motors of about 150 H.P. to drive it. The belt conveyor was several hundred feet in length, and the dump rose to a height of nearly 200 feet at one time.

There is a considerable contrast in the apparatus required for the present method of conveying the tailings to a slimes dam on the flat by means of mixing water with the tailings and pumping them away.

On the Great Boulder mine the tailings were originally disposed of in a somewhat similar manner, but in this case a Bleichert aerial dumping tram system, consisting of a heavy structural steel framework, carrying an endless rope conveying the trucks to the top of the dump, was in use. The driving motors, 30 H.P., were installed at lower end. This also has been superseded by pumping the tailings away with a centrifugal pump. The tailings are now pumped to dams on the flats, near Hannan's Lake, about a mile from the mine.

This change in the method of disposing of the tailings was made possible by arrangement with the Water Supply Department supplying the water at a cheaper rate for this particular purpose.

A 90 H.P. motor on another mine drives eight 5-ft. Wheeler grinding pans, and a centrifugal pump. The load, with all the pans and shafting, is 80.2 H.P., and the average horse-power taken by each pan is 8.4 H.P. per pan. These pans take up to 14 H.P. each when new shoes are fitted and until they are worn down for a few days.

When stamp batteries were in greater use than now, there were several motor driven.

A 30-head (1,050 lb. stamps) mill driven by an 80 H.P. motor, and a 15 H.P. motor on the rock breakers, running constantly, consumed 51,000 units for a 30-day month on the average. The same plant, including also a 30 H.P. motor on

conveyors and treatment plant and 5 H.P. on a mixer, used a total of 70,700 units per 30 days.

Another mill using 20 head of 1,000 lb. stamps, driven by a 50 H.P. motor and having two 5 H.P. motors in addition on pumps, consumed 20,000 units monthly, with 10 head constantly running and 10 head on customs work constantly employed, except when cleaning up parcels. In this case the treatment plant was much more simple than in the preceding.

Electric drive of the saw-milling plants on the mines is very satisfactory. On the Great Boulder a 75 H.P. motor has been driving the mill for many years, although with heavy logs the momentary demand rises to 125 to 150 H.P. many times every day. All the underground timber is sawn by the mill.

One of the most interesting electric motor installations is that of the Great Boulder Perseverance mine. After the original plant of this mine was destroyed by fire in 1911, the new plant was laid out with the object of using electric power from the Power Company's service. An electric drive was installed throughout, except for air compressing and hoisting. Over 1,400 H.P. of motors are in use. Particularly interesting figures are obtainable on this plant as to the proportion of power required in the different parts of the process.

The Perseverance is one of the few mines where such complete figures as to the current consumption of the different sections of the plant can be obtained, as the feeders are run from the main switchboard, and each supplied through a separate feeder panel and recording watt meter.

The current from the sub-station is brought into the switchboard room on overhead cables to the centre panels of the board, where the mine recording meters are installed. Continuous current for operating an electric locomotive which conveys away the tailings is obtained from the duplicate motor generators installed at the end of the switchboard, and continuous current is also used from these sets for lighting the mine. The lighting load is about 20 kilowatts.

The ore is conveyed from underground into the breakers installed near the main shaft, and from the bins of these breakers is taken by belt conveyor to the ball mill plant for finer crushing. Eight No. 8 ball mills are in use, and each of these is driven by a 75 H.P. A.E.G. motor.

The ore then passes through conveyors to the roasting furnaces, and, after roasting, to the tube mills and grinding plant, then to the agitating plant, where the cyanide solution is added, from there to the filter press plant, where the gold solution is extracted, and the tailings are then conveyed away to the dump by an electric tramway.

During a typical month, when crushing 22,000 tons of ore, the total current consumption was 515,960 units. The percentage of the total consumption and the units per ton used in the different treatment operations was as follows:—

	Percentage of Total.	Units per Ton.
Underground, which includes such pumping and underground conveying as is done (there is very little water)	3.56	0.837
Crushers and Conveyors	1.54	0.356
Ball Mill Plant	50.30	11.768
Roasting Plant and Conveyor	7.84	1.965
Tube Mills	6.41	1.490
Agitators and Grinding Pans	18.71	4.367
Filter Presses and Pumps	5.86	1.356
Miscellaneous, including Fitting, Carpenter's Shop and Foundry	0.42	0.094
Motor Generator for Lighting and Signalling	2.51	0.571
Motor Generator for Residues Locomotive	2.85	0.649

A total of 515,960 units per month, or 23.453 units per ton of ore treated.

It is notable that one half of the total power used by the treatment process from mine to tailings dump is used in the fine crushing by the ball mills.

On one occasion a contract was made by the Power Company to supply a mine, which already had a 550 volt, 50 cycle, system supplied by their own turbo generator, which was shut down, and the current supplied from the Power Company's circuits at 550 volts, 40 cycles. About 800 H.P. of motors were involved, and it was anticipated that some of the motors at least would not carry their loads at the lower frequency. The voltage difficulty was overcome by installing a special auto transformer on the feeder to this mine, which was on the same sub-station as other consumers. The auto transformer is rated at 80 kilowatts, and reduces the voltage to 440 on the whole of the mine supply, giving the correct power factor on the motors, which have worked satisfactorily and are all doing the work they did before changing over. It was, of course, necessary to alter pulleys to obtain the right speeds. The change over was effected at the mine at one week-end without interruption or subsequent trouble.

The water reticulation of the Kalgoorlie and Boulder district is from a reservoir located on Mt. Charlotte, Kalgoorlie, into which the water flows from the main pipe from Mundaring. Some years ago the Water Supply Department constructed a 10,000,000-gallon reservoir on the flat ground south of the

town to serve as additional storage when the main pipe line required repairs. The water from this storage reservoir is pumped to the high level reservoir by a centrifugal pump, direct driven by a 3,300 volt induction motor. The pump capacity is 2,090 gallons per minute, and the head 230 feet. The set runs at 1,170 r.p.m. The use of the 3,300 volt motor saved the expense of transforming, and has given every satisfaction. The pump is only operated at intervals when the pipe is under repair.

Induction motors (squirrel-cage first, and slip-ring secondly) are preferred by the mines, owing to their hardy construction.

Almost the whole of the mine load is induction motors, and the power factor of the Power Company's system correspondingly low.

Some years ago several self-starting synchronous motors were purchased by the Power Company for the purpose of inducing the mines to use them and improve the power factor of the feeder and general system. These machines are 80 H.P. capacity and 125 K.V.A. rating. Each is fitted with its own exciter and drives through a clutch pulley. The switch gear, which is complicated but "fool-proof," is iron clad.

The machines, including the pulleys, have given complete satisfaction. Some interesting figures were obtained of the effect on the power factor of using these motors.

One was installed on a mine, where the total feeder load was between 500 and 600 kilowatts. The motor was belted to the stamp mill and performing about 50 to 60 H.P. useful work. The field of the motor was adjusted for full load current, which gave a power factor on the motor itself 0.56 leading.

The effect of this at different points on the feeder was:—

At Mine Switchboard—

Without motor, P.F. 0.80 lag; with motor, 0.99 lag to unity.

At Sub-station supplying the Mine and also other circuits—

Without motor, 0.76 per cent. to 0.78 per cent. lag; with motor, on 0.95 per cent. to 0.97 per cent. lag.

At Power Station end of H.T. Feeder (1½ *miles long*)—

Without motor, 0.77 per cent. lag; with motor on, 0.93 per cent. to 0.95 per cent. lag.

This improvement was a great assistance to the lines and generators in hot weather, and much improved the voltage at the consumers' end.

(17th October, 1918.)

RAILWAY ELECTRIFICATION.

By William H. Taylor.

In accordance with a request from the President to contribute a paper this session, I have chosen a subject which has engaged my attention for some time, and I trust will prove of interest to you, namely, "Railway Electrification."

I have not dealt with local conditions, but principally with systems in England and America, where railway electrification has made considerable headway in the past ten years.

Railway Electrification.

The fact that in the past twenty years over 3,000 miles of railways have been converted from steam to electric working, and that the greater portion has been converted during the past ten years, is an indication of the favour in which electric working has been received by those controlling steam systems, and that the reason for such conversions is in 75 per cent. of the cases from financial reasons brought about by competitive systems of transit, such as tramways, inter-urban and urban railways, cheaper in operation and offering advantages over a slow and expensive steam system.

The large companies in England and America controlled by men of acknowledged foresight in finance and economics, would not have embarked on schemes of electrification out of sentiment or for spectacular effect, but for the reason that by so doing their dividends would be increased and greater prosperity result to their companies.

In the minds of many, railway electrification is considered to be a refinement to be indulged in as a luxury, and that there are no gains to be derived thereby, also that a few miles, say 60 or 80, is the limit. This, however, is not so. The Chicago, Milwaukee and St. Paul's Railway Co. are operating electrically 440 miles of their main line system between Harlowton and Avery, crossing the Rocky and Bitter Root Mountains, where at one point an altitude of 6,400 feet in reached. I will refer to this line again, when considering the technical aspects of various systems.

The first electric locomotive was exhibited in Berlin in 1879, and the earliest important electric railway was the City and South London, a deep level tube, constructed in 1890.

The first steam railway to be changed to electric working was, as far as can be ascertained, the Nantasket branch of the New York-New Haven system, in 1895.

The earliest conversions to electric traction in Europe were those of the Paris, Lyons and Mediterranean railway, in 1900, while the first in England was the Mersey Tunnel railway, in 1903.

It was not, however, until 1904 that the Lancashire and Yorkshire and North-Eastern Railway Cos., in England, and the Long Island Railway Co., in America, converted their important sections of steam railways, consisting of dense and varied traffic over considerable distances. The large systems now in process of changing from steam to electric are those at New York, Buenos Ayres, Melbourne, and London, though with regard to the latter a great portion has been held up due to the war, but will be resumed as soon as conditions are again normal.

Reasons for Electrification.

Several reasons have led to the adoption of electric traction for railway work. Perhaps two of the most important are the ease with which a greatly improved train service can be given at lower operating costs, and the question of ventilation where tunnels are concerned. Numerous instances where the use of electric traction was decided upon for one or all of these reasons are given. In the case of the underground and tube lines in London, the Mersey Tunnel Railway, and underground lines in Paris, Berlin, Hamburg, and New York, it was financially necessary to run a very heavy and fast service of trains, while the importance of the question of ventilation is obvious from the nature of the lines. In the case of the Tyneside lines of the North-Eastern Railway, and the London, Brighton and South Coast Railway, the neighboring tramway competition necessitated a frequent service of fast trains, which electric traction is particularly fitted to give, and which did arrest the loss of traffic, and changed a decreasing traffic into an increasing one.

Advantages of Suburban Electrification.

A regular and more frequent service throughout the day, since each train unit, consisting of, say, three coaches, can be operated separately; it is clear, therefore, that it is possible to run trains consisting of one train unit or even only one motor coach during slack hours, and two or three train units at times of heavy traffic, consisting of six or nine coaches. The cost of electrically operating the lighter trains is small, since under these conditions the cost of electrical energy, cleaning of coaches, repairs and maintenance to coaches, and electrical equipments, is directly proportional to the coach mileage.

This renders it financially possible to give a regular and frequent service of trains throughout the day, regularity of the service being maintained even during slack hours by trains consisting of one unit only, and it has been found that where

a change from steam to electric working has been made that such a service greatly stimulates the increase in traffic.

HIGH SPEEDS.

The use of a high acceleration improves greatly the scheduled speeds which can be obtained, for given lengths of run, and of stop, and by the use of electric traction such an acceleration can be obtained at a reasonable cost, both in the installing of the plant for the tractive power to develop it, and in operating it, and the scheduled speeds for given lengths of run and stop can be materially improved over steam speeds. We know that the multiple unit system of train operation is perfectly suited to the development of high accelerations, since upon this system the whole weight of the trains can be utilised for adhesion if required, by using all motor coaches. It is usually both unnecessary and undesirable to go so far as this, as traffic conditions have not made such necessary on any system so far in operation.

Practical accelerations are limited (apart from the question of providing motive power for the trains) by the fact that high accelerations impose unpleasant conditions upon those occupying the train. With very high accelerations (say two miles per hour per second) not only does the weight and cost of the electrical equipment become excessive, but travelling becomes uncomfortable. Sufficient motive power can be provided and adhesion obtained for acceleration up to 1½ miles per hour per second if the train unit consists of one motor coach and one trailer coach, the four axles of the motor coach being each motor driven. The advisability of the use of such high accelerations depends upon the length of the run, length of stop and schedule speed required.

The acceleration of steam trains is much lower than this —it is of the order of .3 to .5 miles per hour per second with, say, a six-coach train. Further, the acceleration of the steam train at starting depends upon the weight of the train, while with the multiple unit system of electric working the acceleration is independent of the actual number of coaches to the train, since the motive power is proportional to the number of motor coaches used. While there is a wide possibility of improving upon the steam speed acceleration generally used, say from .5 miles per hour per second, to the practical figures with electric working of 1.5 miles per hour per second, the actual increase of speed adopted must, naturally, be subject to the particular conditions of the system under consideration.

The adoption of too high an acceleration increases the capital cost unnecessarily, also the operating costs, since the trains are run at a higher speed than necessary to maintain the schedule.

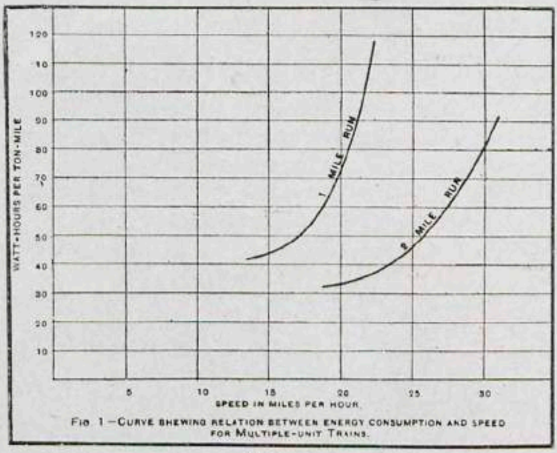

FIG 1 —CURVE SHEWING RELATION BETWEEN ENERGY CONSUMPTION AND SPEED FOR MULTIPLE-UNIT TRAINS.

Fig. 1.

Figure 1 shows that the energy consumption rises rapidly as the speed increases, for a given length of run.

It will be clearly seen that higher scheduled speeds can be adopted economically for long runs, but not for short runs.

The whole gist of the choice of speeds with stopping trains for comparatively short runs is that high speeds can only be secured by accelerating rapidly, and the higher the acceleration the more costly is the electrical equipment for the trains, and the higher the maximum speed the greater is the energy consumption. Very high speeds for short runs are costly, both in capital outlay and operation.

A considerable improvement can, however, be made over steam speeds for any suburban service, and, at the same time, the cost of the electrical equipment and the energy consumption can be kept within reasonable and commercial limits.

More Economical Employment of Train Crews.

Train crews can be more economically employed, due partly to the higher speeds, by which each crew can perform a higher train mileage daily, and partly to the absence of locomotives. When the multiple unit train reaches its terminus, all that needs to be done is that the carriage be opened up for ventilation for a few minutes, and the motor-man to go to the other end of the train.

On the Metropolitan District Railway of London, at the Richmond and other western termini, the trains run in empty, fill, and run out again on the return journey, the lay over in

many cases not being more than three or four minutes. At these points the traffic is very heavy.

Economy in Coal.

A very important point affecting the coal economy of steam locomotives is the stand-by coal losses. The fires have to be lighted, periodically cleaned, also, under certain conditions, banked so as to maintain the full boiler steam pressure all the time that the locomotive is standing about doing nothing, by which is meant the time it is in the hands of its crew, and the time it is in preparation for going into service.

An exhaustive investigation was made by the United States Government into the question of stand-by losses of steam locomotives, and it was ascertained that in the United States something in the order of 20 per cent. of the total coal used per annum by locomotives is wasted in stand-by losses.

These stand-by losses are entirely eliminated in the case of the electric locomotive, owing to the fact that the electric locomotive only consumes power when it is performing useful work, therefore only incurring expense at such times for power, and not when standing idle, as in the case of a steam locomotive.

Engine Men.

The process of preparing a steam locomotive for duty involves a considerable expenditure of time and labour, and in addition to cleaning, lubrication and overhauling at not infrequent intervals, the fire boxes have to be raked out, fire bars renewed, smoke boxes and tubes cleaned, and the boilers blown down and washed out, the time between the operations depending upon conditions.

In contrast to this, the electric locomotive is always ready to take the road without preparation, the little attention required being usually done by the crew itself while in charge of the engine.

Visits to the running sheds are practically only required by electric locomotives for the purpose of cleaning, inspection of brake blocks and the less accessible parts underneath. The motors, if they are kept clean internally and receive a small amount of attention, are always ready for immediate use.

Water.

Water for boiler feed purposes is always a source of anxiety, both in the quantity used and the difficulty of obtaining it suitable for the purpose, if not the cost of treatment, and the damage which may be caused, should it contain corrosive properties; in addition, the cost of water is usually a very important item on the cost sheets.

Running Sheds.

The running shed expenses are reduced by elecrtic locomotives to:—

(*a*) Cleaning, which involves only a fraction of the labour incidental to the cleaning of a steam locomotive.

(*b*) Adjustment and removal of brakes.

(*c*) Provision of lubrication, brushes for commutators.

Compare these with those under steam conditions, and it will be found that the staff required at a steam running shed is very much in excess, as boiler makers, blacksmiths, fitters, fitter labourers, tube cleaners, and general labourers, etc., are required, whereas with electric working these will be reduced to two or three electrical fitters for 20 to 30 electric locomotives; on a certain system in Switzerland, one man looks after ten single-phase locomotives of large size.

The reason for this is obvious. With steam locomotives there are boilers, boiler fittings, motion work, with its numerous component parts, that require attention, while the electric motor has only a revolving armature, two gear wheels, four bearings, and a commutator, all of which are enclosed and automatically lubricated in the case of the bearings and gear wheels.

The entire motor can, if necessary, be changed in four to six hours, which is equivalent to a new boiler, or a complete change of motion work or cylinders on a steam locomotive, which could not be done under days.

Double Heading.

With steam locomotives, when double headed, each is controlled by a separate crew, therefore it is difficult to get each locomotive to take its proper proportion of the load, while the second locomotive's crew receives the smoke and cinders from the first. In the case of electric locomotives there are no objections to double headings if desired, as both can be electrically coupled and operated as one unit, dividing the load equally, and not at the discretion of the crews.

Choice of Systems of Electrification.

There are four general systems of electrification:—

1. Single phase, Alternating Current.
2. Three phase, Alternating Current.
3. Split phase, Alternating Current.
4. Direct Current.

Single Phase.

The single phase system has been used both for main line and suburban electrification, and much controversy exists as

to the relative advantages between it and direct current, but it is generally admitted that for very dense traffic it has not the advantage of the direct current system.

It is not the system which I would feel justified in recommending where only very dense suburban traffic is being dealt with, but where a 15 or 30-minute service is the minimum, I am of the opinion that the single phase system has much to recommend it, and it shows to advantage where long distances have to be covered by only a few trains.

The capital cost of rolling stock is higher than with direct current, but against this must be set lower operating costs, as no sub-stations are used, except at long intervals, also that no rotating machinery is in use, with its consequential upkeep. If a new power station is being built, single phase generators of low frequency would be installed. If a system existed having three-phase generators, it would be necessary to install motor generators of low frequency and delivering single-phase current.

Only one overhead contact line is necessary, which can be operated at 11,000 volts with safety and in several instances 15,000 volts is being used.

There was in 1915 the following comparison of mileage of the various systems in use in the United States of America:—

S.P.	1,490 miles
D.C., 1,200-1,500 volt	2,810 ,,
D.C., 2,400-3,000 volt	910 ,,
Total D.C.	3,720 ,,

In regard to the single phase system, I consider that too much is made of the superiority of direct current. The course I consider should be adopted is to concentrate on single phase equipment and make it lighter for the same duty as direct current, when it would take precedence over it for all services, especially main line work. The time is not far distant when we shall see the single phase system with its many advantages gradually taking its proper place in railway work, but so far it has its limitations.

Three Phase System.

Several notable examples of three phase railways are those of the Valtallina Railway, Italy, the Govi Line and the Savoni-Genoa, the first two being passenger and the latter a high speed passenger and freight line. The Genoa-Savonia line has a normal speed schedule of 100 kilometers per hour. The pressure on the contact line is 3,000-3,500 volts, at a frequency of 15-16 cycles per second.

Split Phase System.

This is the system which has been adopted for the Norfolk and Western Railway, in Amercia. Single phase current is

supplied to the overhead contact line, and converted to two phase for the locomotive motors by means of a phase splitting converter.

Direct Current System.

The introduction of high pressure direct current has been received with such favour that exponents of single phase have temporarily taken a back seat. When 600 volts was considered the limit, long distances with D.C. were out of the question, but with single phase no difficulties were presented.

In 1900 the Paris, Lyons and Mediterranean Railway was electrified at a pressure of 600 volts.

In 1904 the Lancashire and Yorkshire Railway electrified their Liverpool-Southport line, and in the same year the North-Eastern Railway electrified the first section of the Tyneside suburban system, to be followed in 1915 by a main line mineral section between Newport and Shildon, to which I will refer later.

In 1914 the Lancashire and Yorkshire Railway electrified their Burg-Holcombe Brook branch, the pressure being 1,200 volts. A third rail is used in place of the customary Catenary construction. The performance of a third rail at 1,200 volts is being watched with considerable interest.

At the present time English engineers do not show much tendency to exceed 1,500 volts, although there is one experimental line operating at 3,000 volts in the Midland Counties.

The American engineers have used 3,000 volts on the C.M. and P. Railway, with, it is said, satisfactory results.

In direct current systems, I am of the opinion that the limiting factor will not be the motors, but the converting machinery, as the more this becomes complicated and expensive, the more will single phase show to advantage. The higher the pressures used on the contact line, the higher the pressure necessary on the commutator or commutators of the converting apparatus.

In the case of the C.M. and St. Paul Railway, where 3,000 volts is in use, the conversion is by motor generator sets, two 1,500 volts generators being connected in series. This cannot be as efficient as two rotary converters with their transformers. Assuming 100 per cent. load factor, the efficiency of the motor generator sets will be 90.5 per cent., against the same capacity of rotary converters of 94.5 per cent.

There is no difficulty with 1,500 volts on one commutator, therefore it would appear that this will be the pressure used in the greater number of conversions which have yet to be made. It is noteworthy that American engineers have used motor generator sets for the heavy duty lines, whereas English

engineers have used 1,200-1,500 volt rotary converters for important services.

TYPICAL RAILWAY SYSTEMS.

A typical American example is the Norfolk and Western Railway, which operates a 29-mile section, between Vivian and Bluefield, in the State of Virginia.

The total track mileage is 97, including sidings, etc.

The east bound trains ascend a grade of 1.5 per cent, for some distance, with one portion of 2 per cent. The 1.5 per cent. is the Elk-Horn tunnel, which is 4,000 feet long.

This line was put into operation in May, 1915, and represents a recent adoption of single phase for main line electrification. The locomotives used, of which there are 12, weigh 240 tons, the motors being the split phase type. Current is collected by pantograph from the overhead line, which is operated at 11,000 volts, 25 cycles. Trains weighing 3,380 tons, including a 240-ton locomotive, are hauled between Vivian and Bluefield at a speed of 14 miles per hour. This was formerly done by three Mallet locomotives, each of 240 tons; the speed was then only seven miles per hour.

Such a train weighed 3,620 tons, or 7 per cent. more than the electric trains. The speed through the Elk-Horn tunnel had to be reduced below 7 miles per hour, in view of the smoke and fumes. Electric trains maintaining a speed of 14 miles per hour can be despatched through the Elk-Horn tunnel at the rate of a train every three minutes, as against a steam train every seven minutes. Each locomotive's weight is made up of 227,000 lbs. of electrical equipment and 310,000 lbs. of mechanical equipment.

The locomotives are capable of exerting a tractive effort of 68,000 lbs., corresponding to 2,600 H.P., at 14 miles per hour, and 40,000 lbs. at 28 miles per hour, corresponding in this instance to 30,000 H.P., which is the continuous rating of the locomotives.

SINGLE PHASE RAILWAYS.

On the Swiss railways single phase has been extensively adopted for electrifying their mountain railways, and several difficult problems had to be overcome on the pioneer lines changed to electric working.

An important conversion was the St. Gothard tunnel, from steam to complete electric. For this single phase has been used. The contact pressure is to be 15,000 volts, but in the early stages only 7,500 volts is being used. The frequency is 16 cycles per second.

One of the most recent conversions is that of the Berne-Lotchsberg Railway. This line gives direct access to the "Simplon," and consequently to Italy, from the north-west

portion of Switzerland and those more central districts that gravitate towards Berne and the Berenese lakes. This line is of importance to international passengers, as it shortens the distance between the important cities of France and Italy by many hours. This line is operated at 16,000 volts single phase, the frequency being 15 cycles per second.

The locomotives used on this line are capable of developing 2,000 H.P. continuously.

The line being of recent origin, is an indication of the faith which Swiss engineers have in single phase for heavy main line service, operating the severe grades and hauling heavy trains.

SINGLE PHASE SUBURBAN RAILWAYS.

There is only one example of a single phase suburban railway in England, and this is the South London Elevated, which serves the south side of London, and runs over the joint systems of L.C. and D. and S.E. Railways. This line has borne the light of severe criticism by advocates of D.C., but so far it has not proved the failure predicted. In my opinion the weakness lies only in the fact that all the London railways have adopted D.C., which makes inter-running impossible—a feature alone sufficiently important to condemn using single phase for one section of a city system only, bounded, as it is, on all sides by D.C. railways.

	Continuous Train.		Single-phase Train.	
	For Southport service.	For S.L.E. service.	For Southport service.	For S.L.E. service.
Trucks .. .. £	815	815	815	815
Coach Bodies .. .. .. £	4,070	4,070	5,200	5,200
Electrical equipment .. £	3,750	1,630	13,500	4,500
Further costs .. .. .. £	590	510	1,050	690
Total costs of train .. £	9,225	7,025	20,565	11,205
Weight of train .. .. tons	118	101	210	138
Cost per ton .. .. £	78.1	69.5	98.0	81.3

The following table gives the relative costs of operating a D.C. and A.C. railway, based on a schedule of 30 miles per hour, the distance between stops 1.32 miles; and 22 miles per hour and .88 miles between stops:—

Schedule speed, miles per hr.	30		22	
Distance between stops, miles	1.32		0.88	
Equipment of train	Continuous.	Single-phase.	Continuous.	Single-phase.
Weight of train .. .. tons	118	210	101	138
Net consumption of electricity at train in w.-hour per ton-mile	96	96	66	.66

Net consumption of electricity at train in kw.-hour per train-mile	11.3	20.2	6.7	9.1
Miles per train per annum ..	54,000	54,000	48,000	48,000
Net consumption per train per annum .. .. kw.-hr.	610,000	1,090,000	322,000	437,000
Gross consumption per train per annum (= 1.3 × net consumption) in kw.-hr. ..	795,000	1,420,000	419,000	569,000
Total annual cost per train-mile for electricity .. .. *d.*	9.45	13.4	5.60	6.05

The Heysham-Lancaster section of the Midland Railway is operated single phase, but this cannot be considered a suburban line, as such are known; it is more of the style known in America as an interurban railway. The traffic is dense for so short a line, there being 60 trains per day each way.

Direct Current Railways.

In addition to the extensive system of underground and tube railways in London, the suburban systems are also in course of conversion, the latest being the London and North-Western, London and South-Western, and the Midland Railway as far as Southend-on-Sea, 35 miles from London. It will then be possible to take a train at Southend and be put down in the very heart of the city in one hour and ten minutes.

These systems have adopted direct current at 600 volts, so that the benefits of inter-running can be obtained, in preference to gaining one or two per cent. in efficiency by using a higher pressure.

On all the London railways, the third rail has been used. In the case of the Underground and District, four rails are used, the running rails being insulated from the conductor rails.

It is certain as conditions are again normal that the whole of the remaining portions of the London suburban railways will be converted to electric working.

Main Line Electrification, England.

An important change has taken place recently on the North-Eastern Railway Co.'s system, which marks the first main line of a heavy character to be converted to electric working in England. The section referred to is the Shildon-Newport branch.

Some historical interest is also attached to this route, since the track runs over a portion of the original Stockton to Darlington Railway, the first public railway on which steam locomotives were run for the conveyance of passengers and goods. This line was opened for traffic in 1825, and two of

the original locomotives are still to be seen on the Darlington station of the N.E.R. Company.

The fact that the first trial in England of the electrification of heavy freight traffic on a large scale should be carried out on this section is noteworthy.

The route has a length of approximately 18 to 19 miles, and connects the mineral sidings at Shildon, which forms one of the largest marshalling yards in Great Britain, with the Eremus sidings at Newport, near Middlesborough.

A considerable portion of the sidings have been electrified, there being in all about 50 miles of single track.

The overhead system has been adopted, working at a pressure of 1,500 volts. The type of construction is shown in Figure 2.

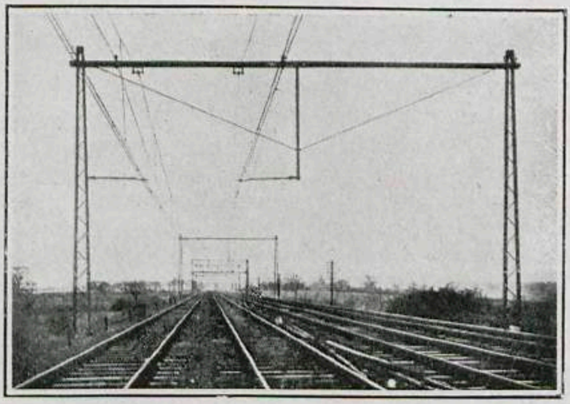

Fig. 2.

The contact line consists of two hard drawn copper conductors each of .155 square inches sectional area, for the main line; on sidings one contact line only is used.

The contact wires are supported from steel catenary, to which the contact wires are clipped at 15 feet intervals. The normal span is 300 feet on tangent track, and on curves this is reduced to suit the conditions of same.

The feeder cables are carried on the supporting structures. These are .109 square inch.

To limit the sag due to variations of temperature as far as possible, automatic tensioning is used, the tensioning points being 1,100 yards apart. Tensioning weights are hung in the centre of the supporting structures by means of chains passing over pulleys, of sufficient capacity to maintain the normal line tension under all conditions.

A tension of one ton is used on spans of 300 feet, which maintains the contact wire taut under all conditions. The contact wire is divided into sections, which are arranged to come at tension points, there being bridged over with switches, operated from the ground.

The running rails are used for the return current, being bonded across the fish-plates with bonds having a sectional area of .109 square inches. They are cross-bonded every 300 feet between the two inner rails of adjacent tracks at the same intervals, the bonds in the 6 feet way being midway between those in the 4 feet way.

The power is furnished by the interconnected system of the North-East Coast, which I have described in my paper before this Institution, into two sub-stations, situated at Aycliff and Eremus.

The Aycliff sub-station contains two 800 K.W. rotary converters, each consisting of two 400 K.W. sets connected in series to give the line pressure of 1,500 volts, the machines, of course, being each of 750 volts. The machines are capable of carrying an overload of 50 per cent. for two hours without commutating difficulties, and 100 per cent. for ten minutes. These machines have taken overloads up to 200 per cent. without flashing over. On account of the high commutator voltage, and to minimise the damage due to flashing over when sustained short circuits are on the system, the operating parts of the brush gear are entirely covered with insulating material, and the commutator by a fireproof shield.

Tests were carried out to determine what load could be suddenly thrown off without flashing over. A load amounting to five times full load was thrown on, and automatically thrown off, seven times. Three times the machines withstood this test without flashing over. Between the tests the commutator was not touched.

The Aycliff sub-station is supplied at 20,000 volts from two independent overhead lines, and Eremus from underground cables in the Middlesborough district, at a pressure of 10,000 volts.

The high tension switchgear in both sub-stations is of the Ironclad type, manufactured by Reyrolle.

The low tension switchgear is of cellular construction, similar to that used on high tension alternating current systems, and is mechanically remote controlled.

The freight locomotives were designed and built at the N.E.R. Co.'s works at Darlington, and the electrical equipment at the works of Messrs. Siemens Bros., Stafford, England. They are designed to haul a load of 1,400 tons at 25 miles per hour on the level.

The motor equipment of each locomotive consists of four totally enclosed motors, each driving one axle through single reduction gearing, the face dimensions of the pinions being 3 11-16th. A pinion is mounted on each end of the motor armature shaft, and meshes into a corresponding gear wheel mounted on the running axle, the gear ratio being 4.5 to 1.

The motors are coupled permanently two in series, two on each bogie and operating series parallel. The control is electro-magnetic. Each motor is capable of developing 275 B.H.P. at a speed of 20 miles per hour, or 1,100 B.H.P. for the locomotive complete.

The motor equipments are capable of exerting a torque sufficient to skid the wheels, under normal conditions of rail, and will exert an average torque of 28,000 lbs. at the tread of the wheels, when starting under normal conditions. The motors and gearing is designed to run at a speed of 45 miles per hour without injury, but the normal speed will be 25 miles per hour.

The power consumption for the trip from Shildon to Newport, an average of 18 to 19 miles, was 453.3 units = 25.1 units per train mile = 31.3 watt hours per ton mile. Assuming elecrtic current at .6 pence per unit at the locomotive, the cost to haul an 800-ton train from Shildon to Newport would be 15 pence per train mile for power, or .0187 pence per ton mile.

Cost of Operating Multiple Unit Trains.

I would like to deal here with the cost of operation, as it refers to other than main line freight trains, particularly the multiple-unit suburban train. As I have previously mentioned, the power consumption varies as the weight of the train. It is obvious that the proper course is to reduce the weight of the trains at hours of light traffic, and increase them at the heavy hours, as would be done with any power consuming apparatus which is not performing revenue earning service.

The following table is for a train of three, six and nine coaches, as also a train with 12 for emergencies, also one coach only if desired:—

No. of Coaches.	Pence per Train Mile.	Tons of Train.
Three	3.85	118
Two	2.61	80
One	1.595	50
Six	7.70	236
Nine	10.55	354
Twelve	15.40	472

From the above table it will be seen that a considerable saving can be effected by reducing the weight of the train, under

certain conditions. These figures are based on a run of 8.7 miles with an average distance between stops of 4,600 feet, the stops being of 20 seconds duration. The average watt-hours per ton mile is 60, or 7 k.w.h. per train mile.

The average mileage per annum of steam locomotives compared with electric trains is as given hereunder, and are those of one of the largest systems in England operating both steam and electric trains:—

	Train Miles per Annum.
Steam	20,000
Electric	48,598

The mileage of the following parts of the electric trains will be of interest:—

Item.	Train Miles.
Wheel Turning	30,300
Motor Armatures	171,030
Armature Bearings	87,100
Commutator Brushes	10,900
Collector Shoes	102,000

On a recent test of a railway type box frame motor, the armature bearings have run 54,000 car miles and still in service. This is on a tramways system, with a track not comparable with that of a railway.

Power Consumption.

The Midland Railway's Morcombe to Heysham line, which is single phase, 6,600 volts, 25 cycles, operates trains of 80.5 tons over a distance of 8.1 miles. The schedule speed is 31.4 miles per hour, made up of 15.6 minutes running time, and four stops of 30 seconds each. The round trip is 16.2 train miles and equals 1,300 ton miles. The energy consumption per ton mile averages 40.5 watt hours.

The distance between stops and the schedule speed in M.P.H. are the influencing factors of the energy consumption. A good example is the Great Northern and Picadilly Tube, London.

Distance between Stops in Miles.	Schedule Speed, M.P.H.	Average Speed.	Energy Consumption W.H. Ton Mile.
.18	10.2	12.7	121
.45	15.0	16.9	78
.99	19.5	20.8	59

The following table indicates the increased energy consumption, with an increase in speed, the distance for the run and between stops remaining the same.

Schedule speed in miles per hour.	Energy Consumption in watt-hour per ton-mile for the various values of the distance in miles between stops set forth at the heads of the vertical columns, and for 20-second stops.							
	0.5	0.6	0.7	0.8	0.9	1.0	1.25	1.5
15	68	58	50	—	—	—	—	—
16	78	66	56	50	—	—	—	—
17	93	76	63	55	50	—	—	—
18	114	90	73	62	55	48	—	—
19	—	104	83	70	60	53	—	—
20	—	—	94	78	66	58	47	—
22	—	—	—	95	77	67	54	—
24	—	—	—	—	98	83	65	55
26	—	—	—	—	—	100	78	63
28	—	—	—	—	—	—	89	73
30	—	—	—	—	—	—	104	82

An average energy consumption for suburban lines, having distances between stops of .8 miles, with a 22 miles schedule speed, is 95 to 100 watt-hours per ton mile, reaching 120 under certain conditions of service.

Relative Costs of Operation.

One of the factors which would influence changing from steam to electric working would be the relative difference in the cost of operation of the two systems.

Comparative Costs, Steam and Electric.

	Steam.	Electric.
		£
Train and loco. operating expenses		85,595
Maintenance transmission lines, etc.		624
Operation of sub-station, etc.		5,558
Maintenance of electric locos.		6,800
Total costs	£181,300	£98,577

	£
Saving in operating costs	82,723
Additional revenue due to electrification	16,100
Total gain by introduction of electrification	98,823
Capital cost of electrification	676,055
Interest at 4 per cent.	27,042
Nett saving on electrification .. .. per annum	55,681

Operating Costs of Heavy Mineral Line in America.

Saving per year	£48,000
Cost per ton-mile, steam	.394 pence
Cost per ton-mile, electric and steam combined	.216 ,,
Cost per ton-mile, electric	.178 ,,
Percentage saving due to electric	45.26 per cent.

Butte, Anaconda and Pacific Railway: Locomotive Expenditure, six months, in pence per train mile.

	All Steam.	Pence per Electric.
I. Maintenance of Equipment—		
Repairs	6.5	2.2
Depreciation	1.0	1.2
Supervision	.4	.2
Total	7.9	3.6
II. Transportation Expenses—		
Wages, Enginemen	6.6	3.2
Engine House Expenses . .	1.9	0.9
Fuel and Power	19.9	7.0
Water	0.3	—
Lubrication	0.6	0.2
Other Supplies	0.3	0.2
Total	29.6	11.5
Total I plus II . .	37.5	15.1

Traffic: 80,000 locomotive miles per annum.

Comparative cost:—

Steam: $37.5 \times 800{,}000 \div 240 =$ £125,000 per annum.
Electric: $15.1 \times 800{,}000 \div 240 =$ £51,000 per annum.

Annual saving = £74,000 per annum by electric traction.

Safety on Grades.

In view of the advance which has been made in the past few years on electric equipment for high voltage D.C. systems, it is now possible to use regenerative control, whereby on the C.-M. and St. Paul Railway 21 per cent. of the energy put into the train is returned to the line. A more important point, however, being the absolute control of the speed when descending grades, and the reduction in wear on brake blocks and brake gear. To be in a position to descend a grade at a fixed and predetermined speed, settled upon by the controlling authorities, must appeal to them as a safeguard which cannot be obtained with steam trains.

In the case of three-phase railways with properly designed locomotive, a constant speed up and down grades can be obtained —not as with steam, slow up the grades and fast down, to make up for the lost time in ascending. With electric locomotives, if desired, 30 miles per hour can be obtained up a grade of, say, 1 in 40, and 30 miles down, or 30 miles up and 40 down. The speed up the grade is a question of H.P. of the motors on the locomotives, the requisite power being supplied from the power house. In view of the overloads which can be carried by

electrical machinery for periods, say one hour, the weight of equipment can be kept down to that necessary to provide for normal conditions, and grades, etc., if not long, can be negotiated on the overload capacity the motors can carry.

The question of the system to be used for railway electrification is not the all-important factor in coming to a decision as to the benefits of electric working over steam, which is one of operating costs and the increased traffic to be gained; it is immaterial whether alternating or direct current is used, the choice of system being a technical one, providing, of course, it is the most economical one for the particular system.

In conclusion I would mention that the benefits to be derived from a change from steam to electric working are generally in favour of electric, which is apparent from the number of systems which are or have been electrified, which you can safely take was not for any other reason than improved efficiency or to obtain better handling of heavy traffic. For mountain and heavy grade railway systems, electric working stands alone.

If I have not touched on all subjects dealing with electrification it is because the time at my disposal is too short to give other than a few of the general principles which have been followed in the electrification of main and suburban railways.

Comparative Cost between Single Phase and Direct Current.

	Average Train Miles.
Passenger—	
Suburban System: Multiple Unit Trains	1,752,000
Loco. Hauled	704,000
Main Line Loco., Hauled	2,000,000
Goods—	
Suburban	600,000
Main Line	1,920,000
Total Train Miles	6,976,000
Shunting Engine Hours	518,000

Capital Cost.

Power Distribution.	Single-phase. £	Direct Current. £
Transmission System		
Sub-stations		
Electrical Equipments		
Permanent Way and Sidings		
Alterations to Way and Works ..		
Rolling Stock		
	£4,834,700	£4,000,710

Additional Capital Expenditure, Single Phase, £833,990.

Annual Working Expenses.

	Single phase. £	Direct Current. £
Provision and Distribution of Electrical Power—		
Total cost of power at house* (including capital charges)		
Inspection and maintenance of transmission line, operation and maintenance of sub-stations .. (Excluding capital charges.)		
Inspection and maintenance of electrical equipment of the permanent way .. .. (Excluding capital charges.)		
Maintenance of Rolling Stock, including inspection, cleaning, routine overhaul, repairs and renewals		
Total	£128,658	£103,014

Increase in operating costs on single-phase system, £25,644.

*Approximately equal for both systems.

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